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# Preliminary Study of Sources of Inorganic Arsenic

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| Air Pollution Control | Glass Manufacturing | Arsenic | |
| Hazardous Air Pollutant | Arsenic Chemical Manufacturing | | |
| Copper Smelting | | | |
| Lead Smelting | | | |
| Zinc Smelting | | | |
| Secondary Lead Smelting | | | |

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# PRELIMINARY STUDY OF SOURCES OF INORGANIC ARSENIC

FINAL

Prepared for:

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August 1982

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This report is issued by the U. S. Environmental Protection Agency to provide information on sources of atmospheric inorganic arsenic emissions. This report was furnished to EPA by Radian Corporation, 3024 Pickett Road, Durham, North Carolina 27701 in partial fulfillment of EPA Contract Number 68-02-3513, Assignment 18. The contents of this report are reproduced herein as received from Radian Corporation. The opinions, findings and conclusions expressed are those of the author and not necessarily those of the EPA. A mention of company or product names is not to be considered as an endorsement by the EPA.

# PREFACE

On June 5, 1980 EPA listed inorganic arsenic as a hazardous air pollutant under §112 of the Clean Air Act. This action was based on the Administrator's findings that there is a high probability that exposure to inorganic arsenic causes cancer in humans, and that there is significant public exposure to inorganic arsenic which is emitted into the air by stationary sources. Now EPA must determine priorities for detailed studies of source categories for possible development of standards. Major factors considered by EPA in determining priorities include the following:

- the economic and technical feasibility of significant improvements in emission control,
- the ease of expeditious development and implementation of standards,
- the degree of public exposure associated with the emissions and locations of the sources within each category,
- the impacts of other Federal regulatory programs, and
- the economic, energy, and environmental impacts of requiring emission reductions beyond existing requirements.

This report provides preliminary information on seven source categories of inorganic arsenic that will assist EPA in the development of priorities for detailed studies for possible development of standards. Any such standard would be in the form of a National Emission Standard for Hazardous Air Pollutants (NESHAP) and would follow the procedures, including public participation, for developing a NESHAP.

Information on source categories of inorganic arsenic other than the seven source categories studied in this report can be found in earlier reports such as the SRI report "Human Exposure to Inorganic Arsenic (May, 1980)" and the PEDCo report "Extended Source Survey Report for Arsenic (May, 1982)" (see reference list in Chapter 1 of this report). The exposure analysis for the seven source categories studied in this report is found in a companion report "Preliminary Study of Sources of Inorganic Arsenic - Exposure Analysis (August, 1982)."

## ABSTRACT

The seven source categories investigated as emitters of inorganic arsenic are as follows:

- primary copper smelters (exclusive of ASARCO-Tacoma),
- primary lead smelters,
- primary zinc smelters,
- secondary lead smelters,
- cotton gins handling arsenic acid-desiccated cotton,
- glass manufacturing, and
- arsenic chemical production.

These source categories were examined to determine the magnitude of arsenic emissions corresponding to the current or existing level of control, the magnitude of arsenic emissions resulting from compliance with all applicable regulations, and the magnitude of arsenic emissions resulting from the use of estimated best control (EBC) for arsenic. In the report, the term baseline is used for all source categories to denote the lesser of arsenic emissions that are currently occurring or the arsenic emissions that would be expected if the source was complying with all applicable regulations. These regulations include State implementation plans (SIPs), Occupational Safety and Health Administration (OSHA) standards, and New Source Performance Standards (NSPS). A potential EBC for each source category was selected based on whether the emitted arsenic was primarily in a particulate or gaseous form, or in a combination of both forms, and whether the technology had been demonstrated as an effective method of arsenic control within the subject or a similar source category. Once an EBC option was selected, the objective was to determine the incremental arsenic emissions reduction achievable over baseline by implementing EBC. The resultant costs of the EBC increment were also determined.

The arsenic emissions and control data in the report were obtained from published technical papers and reports, EPA data files on arsenic, and from the subject companies within each source category. No source testing was performed for this study. In instances where no arsenic emissions data were available, estimates were prepared using the assumptions and calculations given in Appendix A of this report. All data on the cost of arsenic control

equipment were derived from published cost curves in economic and technical reports. All cost bases and assumptions used in this report are detailed in Appendix B.

The primary copper smelting category includes 14 plants located in seven States that emit inorganic arsenic from both process and fugitive sources. For many of the process sources, Radian's EBC for arsenic control is already being used as a result of the existing particulate matter and sulfur dioxide ($SO_2$) regulations the smelters must comply with. Electrostatic precipitators (ESP's) and contact sulfuric acid plants are used for particulate and $SO_2$ control, respectively. To reduce the occurrence of arsenic vapor emissions, gas coolers prior to particulate control devices are recommended as a requirement of EBC for arsenic. Fugitive arsenic emissions from tapping and materials handling are currently controlled by wet suppression and local hooding and ventilation to a particulate control device or atmosphere. For arsenic fugitives from the converter sources air curtains and secondary hooding systems appear to be viable EBC options. Fugitive arsenic emission sources are not controlled to EBC levels in any of the primary copper smelters. Agreements are currently being reached between OSHA and individual smelters that will result in improvements in fugitive emission control systems. Copper smelting source category arsenic emissions under baseline control are estimated to be 233 Mg (256 tons)/yr. The implementation of EBC is estimated to reduce total arsenic emissions to 119 Mg (131 tons)/yr. To implement arsenic EBC, the copper smelting industry would experience an economic impact of varying proportions based on plant size and current control status. To maintain the current copper industry net present values (NPV), unit product price increases ranging from 0.6 to 4.6 percent would be required.

Currently there are five domestic primary lead smelters, three in Missouri and one each in Montana and Texas. Primary lead smelters have process and fugitive arsenic emission sources, with fugitive sources posing the most significant air pollution problem. All process arsenic emissions sources are controlled by either contact sulfuric acid plants or low temperature (110°C) fabric filters. as dictated by existing State and Federal regulations. For this reason arsenic EBC is assumed to be in place for process arsenic emission sources in the primary lead smelting industry. Fugitive arsenic emissions from primary lead smelters will be affected by the National Ambient Air Quality Standard (NAAQS) for lead, impending lead SIP's, and OSHA standards for lead and inorganic arsenic. It is assumed that when compliance with standards is achieved, fugitive arsenic emissions will be controlled to the level of EBC. Total arsenic emissions from primary lead smelting are estimated to be approximately 43 Mg (47 tons)/yr if EBC control is achieved industrywide.

The primary zinc smelting source category consists of five zinc metal smelters and two zinc oxide smelters that emit arsenic. The four zinc metal smelters that use electrolytic smelting techniques emit arsenic only during the roasting step. All of these plants use contact sulfur acid plants to control roaster $SO_2$ emissions which concurrently control arsenic to the EBC level. The one electrothermal zinc metal smelter also uses an acid plant for its roaster emissions, therefore, EBC is in place at all roaster sources. Electrolytic zinc plants have no arsenic air emissions other than from the roaster. The sinter machine and smelting furnace arsenic emissions from the electrothermal smelter are controlled by a low temperature (110°C) fabric filter, which represents EBC for these emission points. In the zinc oxide plants roaster emissions are also controlled by contact sulfuric acid plants, therefore, EBC is in place for these sources. Other process offgas streams are controlled by low temperature fabric filters such that arsenic EBC is also in place at the majority of these sources. There is, however, a process fabric filter system at one zinc oxide smelter that requires cooling of the inlet stream before EBC can be in place. The current fabric filter operating temperature of 140°C (280°F) needs to be reduced below 110°C (230°F) to limit losses of vaporized arsenic trioxide. At the EBC level, arsenic emissions from the zinc smelting source category are estimated to be 1.2 Mg (1.3 tons)/yr. Arsenic emissions from the zinc source category have predominantly been controlled as a result of SIP and NSPS regulations.

The secondary lead industry consists of 66 plants that are located in 26 States and all ten EPA regions. Arsenic is emitted by secondary lead smelters from process, process fugitive, and area fugitive sources. The predominant sources of process emissions are the smelting furnaces and the refining pots. Process fugitive emissions are generated during charge preparation, furnace operations, and refining operations. Area fugitive sources include raw material storage piles and the charge preparation area. Arsenic emissions are currently being controlled to some extent because of the smelters' obligation to comply with existing regulations for lead and particulate emissions. Fabric filters and wet scrubbers are primarily used to achieve compliance with the NSPS and SIP's that are applicable to secondary lead smelters. These devices have proven effective at controlling process lead emissions, and are anticipated to be equally as effective at controlling arsenic due to the similar behavior of the two compounds. A fabric filter/scrubber configuration was selected as EBC for secondary lead process emissions. The major arsenic emission problem from secondary lead smelters appears to result from fugitive sources. The full implementation and enforcement of the OSHA lead standard and the NAAQS for lead are predicted to have positive effects on arsenic emissions reductions from fugitive sources. Once all applicable standards are met by the secondary lead industry, EBC for fugitive sources should be in place. The use of EBC control in the secondary lead smelting industry, for process and fugitive sources, is expected to reduce arsenic emissions by 22.4 Mg (24.6 tons)/yr. The implementation of EBC in the secondary lead smelting industry would result in a unit product price increase of 1.1 to 1.6 percent in order to maintain current industry NPV.

The cotton ginning source category includes only gins that handle cotton which has been desiccated with arsenic acid. These types of gins are located primarily in Texas and Oklahoma and number about 320. The applied arsenic acid spray forms a residue on cotton plant leaves, stems, and burs which are emitted as gin trash during the seed cotton ginning process. Cyclone collectors are used to control the trash, and consequently arsenic emissions from a gin. Because gin operations are agricultural and seasonal in nature they are not rigidly regulated as air pollution sources. For these gins, EBC control was determined to be a secondary arrangement of cyclones following those presently in use. The particular type of secondary cyclones recommended are known as "long-cone" cyclones. Baseline arsenic emissions from cotton gins are estimated to be about 3.2 Mg (3.5 tons)/yr including both process and fugitive sources. Arsenic emissions under the EBC level are estimated to be 2.4 Mg (2.6 tons)/yr for process and fugitive sources. To implement EBC and maintain their NPV, cotton ginners would be required to increase their unit product price by 0.5 to 2.1 percent, depending on gin size.

The glass manufacturing source category consists of glass plants that use arsenic trioxide or arsenic acid as a batch raw material for the glass melting process. This study identified 15 domestic glass plants that were using and emitting arsenic compounds. The high temperatures of the melt furnace vaporize the amount of arsenic raw material that is not complexed in the molten glass mixture. The vaporized arsenic is entrained in the furnace flue gas and is emitted along with furnace particulate and $SO_2$ emissions. Particulate emissions from glass plants are controlled primarily by ESP's to comply with State regulations. Fugitive arsenic dust emissions from raw materials handling are highly controlled due to OSHA regulations for airborne inorganic arsenic in the workplace. EPA tests have demonstrated that arsenic control efficiencies of 93 to 99 percent are achievable with existing particulate control devices in use at glass plants. For glass plant arsenic emissions EBC is defined as an ESP or fabric filter preceeded by a gas cooling chamber (to reduce arsenic vapor losses). At current regulatory levels, arsenic emissions from the 15 glass plants are estimated to be 51 Mg (56 tons)/yr. If EBC for arsenic were implemented in all plants arsenic emissions are estimated to be about 2.9 Mg (3.2 tons)/yr. The implementation of EBC would require a unit product price increase, to maintain glass industry NPV, ranging from 1.1 to 1.7 percent.

Arsenic chemical manufacture consumes approximately 90 percent of the total arsenic used in the United States. The production of orthoarsenic acid, monosodium methylarsonate (MSMA), disodium methylarsenate (DSMA), dimethylarsenic acid (cacodylic acid), and chrome copper arsenate (CCA) consumes about 90 to 95 percent of the arsenic used for arsenic chemicals. Seven companies with a total of eight plants are producing these significant arsenic chemicals and emitting inorganic arsenic. Arsenic emissions occur when the dry arsenic trioxide raw material is dumped into storage hoppers and process reactors. Arsenic emissions from the source category are well controlled due to the value of the recoverable material and the influence of the OSHA workplace standard for airborne inorganic arsenic. Manufacturers have installed highly efficient hooding or enclosure systems, ventilation systems, and particulate control devices to comply with the OSHA standard and to recover arsenic trioxide dusts that can be used in the process. The existing controls used at arsenic chemical plants to comply with OSHA standards represent EBC for arsenic chemical plant air emissions. Total arsenic emissions from the eight prominent plants are estimated, from data supplied by the manufacturers, to be about 41 kg (90 lb)/yr.

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# 1.0 INTRODUCTION AND SUMMARY

## 1.1 PURPOSE AND SCOPE

On June 5, 1980 EPA listed inorganic arsenic as a hazardous air pollutant under Section 112 of the Clean Air Act.[1] This action was based on the EPA Administrator's findings that there is a high probability that exposure to inorganic arsenic causes cancer in humans, and that there is significant public exposure to inorganic arsenic which is emitted into the air by stationary sources. After listing inorganic arsenic under Section 112, EPA conducted a "Phase I" screening study to gather data on suspected source categories of inorganic arsenic.[2] This Phase I screening study proved to be inconclusive for all the source categories involved, therefore, EPA initiated this second study to finalize the data gathering for arsenic source prioritization.

The purpose of this study is to examine seven stationary source categories of inorganic arsenic emissions and provide information on each to assist EPA in determining priorities for detailed studies for possible regulatory development. The seven source categories are as follows:

- primary copper smelters (exclusive of ASARCO-Tacoma),
- primary lead smelters,
- primary zinc smelters,
- secondary lead smelters,
- glass manufacturing,
- cotton gins (that handle arsenic acid-desiccated cotton), and
- arsenic chemical plants.

These source categories were examined to determine the magnitude of arsenic emissions corresponding to the current or existing level of control, the magnitude of arsenic emissions resulting from compliance with all applicable regulations, and the magnitude of arsenic emissions resulting from the use of estimated best control (EBC) for arsenic. In the report, the term baseline is used for all source categories to denote the lesser of arsenic emissions that are currently occurring or the arsenic emissions that would be expected if the source was complying with all applicable regulations. These regulations include State implementation plans (SIPs), Occupational Safety and Health Administration (OSHA) standards, and New Source Performance Standards (NSPS). A potential EBC for each source category was selected based on whether the emitted arsenic was primarily in a particulate or gaseous form, or in a combination of both forms, and whether the technology had been demonstrated as an effective method of arsenic control within the subject or a similar source category. Once an EBC option was selected, the objective was to determine the incremental arsenic emissions reduction achievable over baseline by implementing EBC. The resultant costs of the EBC increment were also determined.

The arsenic emissions and control data in the report were obtained from published technical papers and reports, EPA data files on arsenic, and from the subject companies within each source category. No source testing was performed for this study. In instances where no arsenic emissions data were available, estimates were prepared using the assumptions and calculations given in Appendix A of this report. All data on the cost of arsenic control equipment were derived from published cost curves in economic and technical reports. All cost bases and assumptions used in this report are detailed in Appendix B.

The source Chapters 3 - 9 present arsenic emissions estimates, arsenic control device technical feasibilities, capital and annualized control cost data, and resulting impacts of additional arsenic control for each source category. The regulatory frameworks that influence the control of arsenic emissions from each of the source categories are discussed in Chapter 2. Recommendations on the ease of possible standards development are made based on the technical and economic feasibility of requiring additional arsenic control and the status of other regulatory efforts affecting arsenic control.

## 1.2 SUMMARY OF RESULTS

Table 1-1 presents a summary of information for each arsenic emissions source category. The data presented in Table 1-1 are specifically derived and/or explained in each of the appropriate source category chapters or their corresponding appendices.

## TABLE 1-1. SUMMARY OF INFORMATION FOR THE ARSENIC SOURCE CATEGORIES

| Source Categories | Number Of Plants | Number Of States Involved | Primary Regulations And/Or Other Factors Affecting Arsenic Emissions Control | Percent Improved Arsenic Control With EBC[a] | Predominance Of Small Businesses | Proportion Of Fugitive Emissions (%) | Incremental Cost Effectiveness Of EBC[b] | Percent Product Price Increase With EBC | Multimedia Impacts Of EBC[o] |
|---|---|---|---|---|---|---|---|---|---|
| Primary Copper Smelting | 14 | 7 | $SO_2$, Particulate SIPs, OSHA Arsenic, NSPS | | No | 42[c] | | 0.6 - 4.6 | Air: +4<br>Water: -1<br>Solid Waste: 0<br>Energy: -1 |
| - Process Emissions | | | | 34 | | | $4200 - 160,000/Mg | | |
| - Fugitive Emissions | | | | 87 | | | $150,000 - 250 million/Mg | | |
| Primary Lead Smelting | 5 | 3 | $SO_2$, Particulate SIPs, NSPS, OSHA Lead & Arsenic, Lead NAAQS | 0[d] | No | 27 | NA[e]<br>$25,000/Mg | NA[e]<br>0.3 | NA[e] |
| Primary Zinc Smelting | | | $SO_2$, Particulate SIPs, NSPS | | | | | | |
| - Zinc metal plants | 5 | 5 | | 0[f] | No | Negligible[h] | NA[e] | NA[e] | NA[e] |
| - Zinc oxide plants | 2 | 2 | | 85[g] | No | Unknown[g] | | | Air: +2<br>Water: -1<br>Solid Waste: 0<br>Energy: -2 |
| Secondary Lead Smelting | 50 - 66[f] | 26 | | | Yes | 70 | $570,000 - 670,000/Mg[k] | 1.1 - 1.6 | Air: +3<br>Water: -2<br>Solid Waste: -2<br>Energy: -2 |
| - Process Emissions | | | Particulate SIP, NSPS OSHA Lead, Lead and Particulate NAAQS | 60[i] | | | | | |
| - Fugitive Emissions | | | | j | | | | | |
| Cotton Ginning | ~320 | 2 | Particulate SIP | 50[i] | Yes | 50 | $3.8 - 9.4 million/Mg[l] | 0.5 - 2.1 | Air: +1<br>Water: 0<br>Solid Waste: -1<br>Energy: -1 |
| Glass Manufacturing | 15 | 9 | Particulate SIP | 94[i,m] | No | n | $97,200 - 206,000/Mg[p] | 0.7 - 1.7 | Air: +3<br>Water: 0<br>Solid Waste: 0<br>Energy: -2 |
| Arsenic Chemical Manufacturing | 8 | 6 | OSHA Arsenic, Economics of Raw Material Recovery | 0[f] | No | 100 | NA[e] | NA[e] | NA[e] |

## Footnotes for Table 1-1.

[a] 0 - no impact
1 - negligible
2 - small
3 - moderate
4 - large
(+) - positive
(-) - negative

[b] Cost effectiveness numbers are expressed as $/unit of arsenic removed.

[c] The proportion of fugitive emissions shown was estimated for the baseline level of control corresponding to the control levels in Table 3-5 of Chapter 3.

[d] Arsenic EBC is projected to be in place for all arsenic emission sources when compliance with existing regulations is achieved.

[e] Not applicable, EBC is in place.

[f] No improvements are noted because all facilities were determined to have EBC in place.

[g] Emission estimates for zinc oxide smelters are speculative due to a lack of published data on the fate of arsenic in the process.

[h] Fugitive emissions from primary zinc metal plants are very low because of the predominance of hydrometallurgical operations.

[i] Represents the industrywide improvement from controlling process emissions only.

[j] No EBC could be defined for area fugitive emissions because of the uncertainty in what types of controls will be required under lead SIPs to meet the lead NAAQS. For process fugitives EBC was determined to be in place, therefore, the improvement would be zero.

[k] Costs are on a per plant basis and are for process control only. The $570,000 cost is for a medium or large plant (18,180 Mg/yr and 36,360 Mg/yr lead production, respectively) and the $670,000 cost is for a small plant (9,090 Mg/yr lead production).

[l] Costs are on a per plant basis, the $3.8 million cost is for a 20 bale/hr gin and the $9.4 million cost is for a 4 bale/hr gin.

[m] Over 90 percent of the reduction occurs by implementing EBC at 3 plants.

[n] Fugitive arsenic emissions are already well controlled due to OSHA regulation for arsenic, see Chapter 8, Section 8.2.

[p] Costs are on a per plant basis, the $97,200 cost is for a 181 Mg glass/day plant and the $206,000 cost is for a 45 Mg glass/day plant. These costs may be overstated due to a potential underestimate of the amount of arsenic used in various sized glass plants. Arsenic usage data is held to be very proprietary by the glass industry.

[q] EBC is based on the control of arsenic only and not other pollutants. $\% \text{ improvement} = \frac{\text{emissions}_{\text{baseline}} - \text{emissions}_{\text{EBC}}}{\text{emissions}_{\text{baseline}}} \times 100$

[r] Reported number of plants varies considerably depending upon the definition of secondary lead smelters. Some plants only refine lead in pot furnaces and do no smelting. Emissions from refiners are much lower than for smelters.

## 1.3 REFERENCES

1. U.S. Environmental Protection Agency. National Emission Standards for Hazardous Air Pollutants; Addition of Inorganic Arsenic to List of Hazardous Air Pollutants. 45 FR 37886. Washington, D. C. Office of the Federal Register. June 5, 1980.

2. PEDCo Environmental, Inc. Extended Source Survey Report for Arsenic. (Prepared for Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency.) EPA Contract No. 68-02-3173. May 1982.

## 2.0 ARSENIC PROPERTIES AND CURRENT REGULATIONS AFFECTING EMISSIONS

This chapter is divided into two sections which discuss the physical and chemical properties of arsenic pollutants and their relationship to air pollution, and the various regulatory authorities which have a role in reducing arsenic air pollution.

### 2.1 PROPERTIES OF INORGANIC ARSENIC POLLUTANTS

This section briefly discusses the physical and chemical properties of inorganic arsenic pollutants and the effects these properties have on air pollution emissions. The major thrust of the section will be toward the properties of arsenic trioxide since this is the most common inorganic arsenic compound.

Arsenic is the 47th most frequently found element in the Earth's crust. Its total occurrence in the crust is estimated at about 0.00055 percent.[1] Arsenic occurs in nature primarily as a sulfide or bound to sulfur, and is often found in association with iron. The most common form of naturally-occurring arsenic, arsenopyrite, (FeAsS) exemplifies this. Metal ore deposits of lead, zinc, gold, silver, copper, and tin are also natural sources of arsenic.[1]

Elemental arsenic is a nonmetal or metalloid that is classified in Group 5a of the periodic table which also includes phosphorus, nitrogen, antimony, and bismuth.[2] The most common oxidation states of arsenic are -3, +3, and +5, with +3 being the most prevalent in inorganic arsenic compounds. Other important properties of arsenic are listed below:[2]

Properties of Arsenic

| | |
|---|---|
| Atomic number | 33 |
| Atomic weight | 77.9216 |
| Melting point | |
| at 1 atmos., sublimes at | 613°C |
| at 28 atmos., melts at | 817°C |
| Density at 20°C | 5.72 g/cm$^3$ |
| Latent heat of fusion | 88.5 cal/g |
| Latent heat of sublimation | 102 cal/g |
| Specific heat at 20°C | 0.082 cal/(g)(°C) |
| Lattice constants at 26°C | a = 2.760A<br>b = 10.548A |
| Hardness (Mohs scale) | 3.5 |

The most important commercial arsenic compound is arsenic trioxide which is also known as arsenous oxide, "white arsenic" and arsenic. Arsenic trioxide is used as the raw material to manufacture the majority of all other inorganic and organic arsenic compounds of commercial importance. A detailed list of arsenic compounds and specific uses is given in Chapter 9, Table 9-1.

Arsenic trioxide occurs as a white solid in several crystallagraphic modifications. The most common form is the octahedral (or cubic) modification known as arsenolite. Arsenic trioxide is appreciably volatile at temperatures above 100°C (212°F) which is important from an air pollution standpoint.[3,4] Table 2-1 presents some vapor pressure data for arsenic trioxide.

### 2.1.1 Arsenic and Air Pollution

Of the seven source categories under study, five are referred to as "hot" sources and two as "cold" sources. The source categories characterized as hot emission sources involve high temperature processes in which some portion of the arsenic component of the materials being processed is volatilized. A large portion of the volatilized arsenic is eventually emitted in the vapor phase if the process exhaust gas temperatures are not reduced by using cooling devices. The primary copper, lead, and zinc smelters, the secondary lead smelters, and the glass manufacturers constitute the hot sources. The cold emission sources, which only emit arsenic as a particulate, consist of the arsenic chemical plants and the cotton gins. The cold sources involve ambient or relatively low temperature [less than 38°C (100°F)] processes that do not volatilize any arsenic components.

As stated before arsenic and its compounds are ubiquitous and are found in close association with many nonferrous metal ores. Table 2-2 lists some nonferrous metal ores and their observed range of ore concentrate arsenic content. When these ores are processed arsenic compounds are released. The predominant source of arsenic and arsenic trioxide in the U. S. is as a byproduct of copper smelting. The arsenic occurs predominantly as the sulfide which in most pyrometallurgical processes, oxidizes to the trioxide. Both the sulfide and oxide are extremely volatile at the temperatures encountered in nonferrous metal production. The arsenic trioxide or sulfide enters the gas stream, and as the gas stream cools down, some condenses and is collected in the flue dusts. However, because of the high vapor pressure of the trioxide, appreciable quantities of the oxide may remain in the gas stream unless it is cooled to below 100°C (212°F).

Not all of the arsenic in the feed materials volatilizes. Some remains in the solid phase and is carried through to the product metal, some is released to the atmosphere in subsequent operations, and some ends up complexed in the slag.

## TABLE 2-1. ARSENIC TRIOXIDE (ARSENOLITE) VAPOR PRESSURE DATA[3,4]

| Vapor Pressure (mm of Hg) | Equilibrium Vapor Phase Concentration (mg As/$m^3$) | Temperature of Arsenic Trioxide (°C) |
|---|---|---|
| $2.4 \times 10^{-7}$ | $3.9 \times 10^{-3}$ | 60-61 |
| $2.5 \times 10^{-5}$ | $4.0 \times 10^{-1}$ | 81-86 |
| $4.6 \times 10^{-4}$ | 7.4 | 101-105 |
| $1.9 \times 10^{-3}$ | $3.1 \times 10^{1}$ | 117-124 |
| $2.2 \times 10^{-3}$ | $3.5 \times 10^{1}$ | 119-124 |
| $2.6 \times 10^{-2}$ | $4.2 \times 10^{2}$ | 149-152 |
| $1.0 \times 10^{-2}$ | $1.6 \times 10^{2}$ | 153.5 |
| $2.7 \times 10^{-2}$ | $4.3 \times 10^{2}$ | 165 |
| 1.0 | $1.6 \times 10^{4}$ | 212.5 |
| 5.0 | $8.1 \times 10^{4}$ | 242.6 |
| $1.0 \times 10^{1}$ | $1.6 \times 10^{5}$ | 259.7 |
| $2.0 \times 10^{1}$ | $3.2 \times 10^{5}$ | 279.2 |
| $4.0 \times 10^{1}$ | $6.4 \times 10^{5}$ | 299.2 |
| $6.0 \times 10^{1}$ | $9.7 \times 10^{5}$ | 310.3 |
| $1.0 \times 10^{2}$ | $1.6 \times 10^{6}$ | 332.5 |
| $2.0 \times 10^{2}$ | $3.2 \times 10^{6}$ | 370.0 |
| $4.0 \times 10^{2}$ | $6.4 \times 10^{6}$ | 412.2 |
| $7.6 \times 10^{2}$ | $1.2 \times 10^{7}$ | 457.2 |

TABLE 2-2. ARSENIC CONTENT OF ORE CONCENTRATES SMELTED IN THE DOMESTIC PRIMARY COPPER, LEAD, AND ZINC INDUSTRIES

| ORE CONCENTRATE TYPE | RANGE OF ARSENIC CONTENT (wt %) | APPROXIMATE PRIMARY METAL CONTENT (wt %) | ARSENIC/METAL RATIO |
|---|---|---|---|
| Copper | 0.004 - 3.8 | 25 | 0.0002 - 0.15 |
| Lead | 0.2 - 0.4 | 60 | 0.0003 - 0.007 |
| Zinc | 0.002 - 0.1 | 60 | 0.00003 - 0.002 |

Inorganic arsenic compounds can also be volatilized and released to the atmosphere any time an arsenic containing material is burned (example, coal combustion) or subject to high temperatures. Many nonferrous metals are recovered as scrap and reprocessed by smelting and refining. When the scrap material is smelted some of the arsenic present as an alloying constituent can be oxidized and volatilized and released into the environment. In glass manufacture inorganic arsenic compounds are added to the batch materials and then subjected to high temperatures. Some arsenic trioxide vapor is released to the environment during these operations. Emissions of inorganic arsenic can also occur when these compounds are being handled and used. For example, during the manufacture of many arsenic chemicals dry arsenic trioxide is the starting point. Some fugitive emissions of inorganic arsenic particulate may occur during the handling and dumping of this raw material.

### 2.1.2 Air Pollution Control

The type of air pollution control most effective on a given source of arsenic will be dependent upon several of the source characteristics, the two most important being exhaust gas arsenic concentration and temperature. Sources operating at temperatures above 100°C (212°F) and handling materials containing arsenic have the potential to emit appreciable quantities of arsenic in the vapor phase. In order to control these emissions, the exhaust gases must be cooled down to allow the arsenic species vapor to condense, and then must be cleaned with a particulate removal device. For example, the mechanism of cooling down vaporized arsenic trioxide to recover trioxide dust is readily demonstrated by analogy to the "kitchens" or brick cooling chambers used by the smelting industry to produce commercial grade arsenic trioxide. As the gas stream exits the last kitchen its temperature is less than 100°C (212°F) and the condensed particulate is 90 to 95 percent pure.[2] A more detailed discussion of the arsenic trioxide kitchens can be found in reference 2.

The efficiency of the cooling/collection device system is a function of the inlet arsenic concentration and the degree of cooling achieved, and is bounded by the equilibrium vapor pressure of the arsenic species present. Figure 2-1 presents a plot of control device inlet and outlet arsenic concentrations vs. temperature for various hot arsenic sources. The data shown were obtained from tests conducted on copper smelter process offgas streams.[3] The figure shows that the lowest arsenic outlet concentrations occurred when the outlet gas temperature was below 100°C (212°F). The curve also shows that the outlet arsenic concentration tracks that predicted from the theoretical vapor pressure curve. There are of course practical limits to the amount of cooling that can be achieved in a given situation. For example, one must avoid cooling sulfur containing stack gases to below the acid dew point or severe corrosion problems can result. Alternatively, these streams with high dew points can be controlled with wet scrubbers where the acid can be easily neutralized.

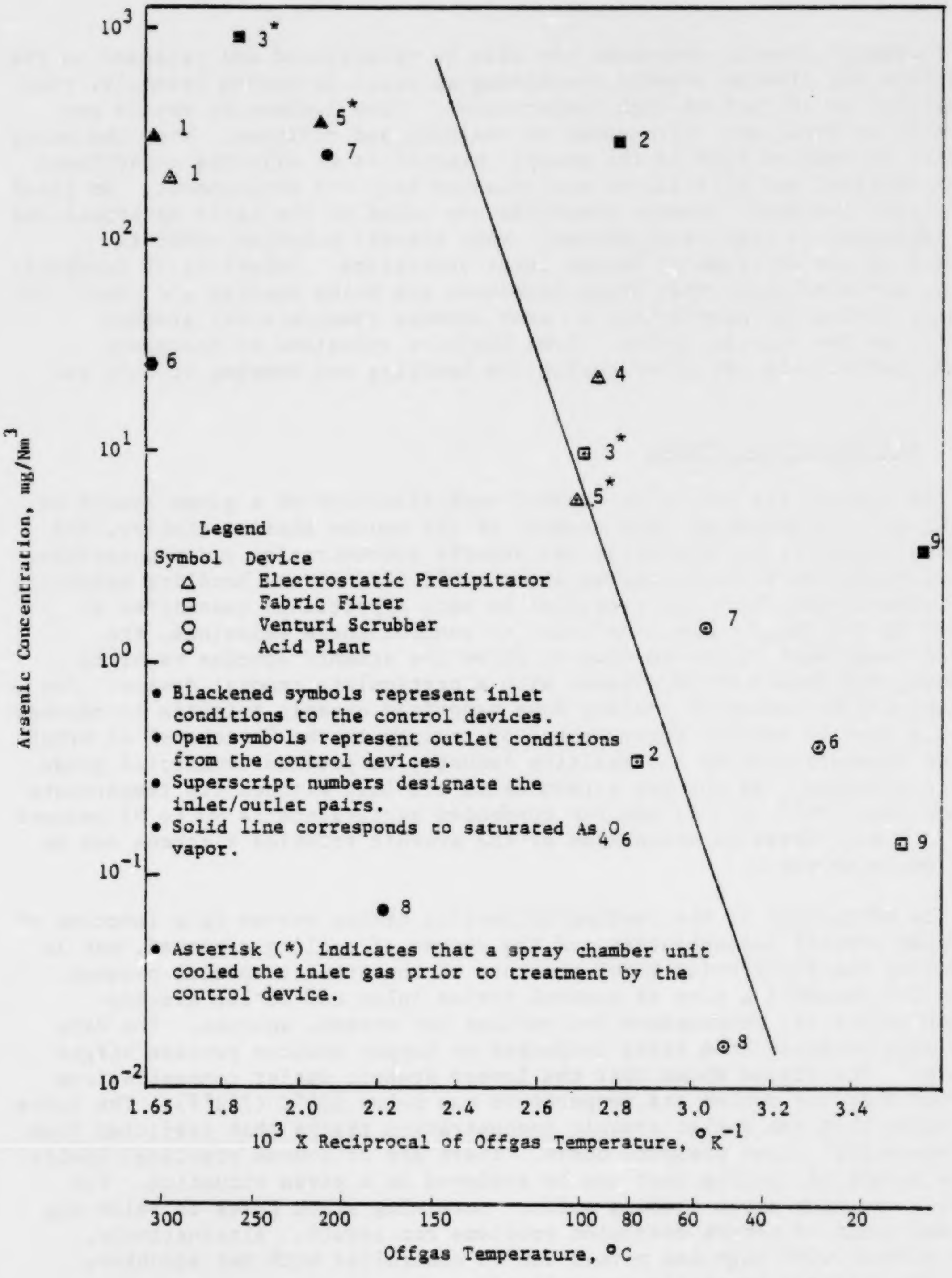

Figure 2-1. Effect of temperature on the performance of arsenic emissions control devices.

Cold sources of inorganic arsenic emissions such as manufacturing of arsenic chemicals from dry arsenic trioxide can be controlled by any particulate control device. In these cases the ultimate performance is not dictated by exhaust gas temperatures.

## 2.2 REGULATIONS AFFECTING THE EMISSION OF INORGANIC ARSENIC

Arsenic emissions from industrial sources are affected by arsenic-specific regulations, particulate and $SO_2$ regulations, workplace safety and health regulations for inorganic arsenic and lead, and national ambient air pollutant concentration limits. The specific influence and application of these regulatory measures on the seven source categories of arsenic emissions are discussed in the following sections.

### 2.2.1 Arsenic-Specific Regulations

No regulations could be identified on the Federal, State, or local level that specifically limit the atmospheric emission of inorganic arsenic on a mass emission or percent reduction basis. Some States and localities do, however, have regulations and guidelines that affect arsenic emission sources and do aid in reducing public exposure to inorganic arsenic. The city of Philadelphia has regulations which identify arsenic as a toxic air pollutant and require all emitters of the chemical to register with the Philadelphia Air Control Board. The level of arsenic emissions from a particular facility is determined and an ambient fenceline concentration from the facility calculated through dispersion modelling. The determined fenceline concentration is compared to an established acceptable ambient concentration for that toxic pollutant to decide whether further controls are required. If the fenceline concentration is greater than the guideline, the city can require best available control technology to be installed.[5,6]

New York State has a similar system for toxic air pollutants which also covers arsenic, however, the New York system is only a policy guide for the environmental control department and is not part of the State's regulatory framework. Threshold Limit Values are used to establish acceptable ambient limits for a toxic air pollutant such as arsenic. Dispersion modelling is used to determine the ambient concentration attributable to the source. The determined concentration is compared to the established acceptable limit and a decision is made by the environmental control agency as to whether further controls are required.[7]

In New Hampshire the general particulate matter process weight regulation is used to control sources where arsenic is emitted as a particulate. The general equation is modified for toxic pollutants such as arsenic by applying a stringency factor. The stringency factor for arsenic is 0.9.[8] Therefore, if a plant were allowed to emit for example, 4.5 kg (10 lb)/hr under the general particulate regulation, they could only emit 4.1 kg (9 lb)/hr if the emissions contained arsenic.

### 2.2.2 Particulate Matter and Sulfur Dioxide Regulations

State particulate matter regulations in the form of State implementation plans (SIP's), and Federal new source performance standards (NSPS) directly affect to varying degrees the extent to which arsenic emissions are reduced from the seven source categories in this study. All seven source categories are affected by SIP regulations, while only primary copper, lead, and zinc smelting, secondary lead smelting, and glass manufacturing are affected by NSPS. The glass manufacturing NSPS, however, is currently under reconsideration by EPA and may be dropped.[9] In the process of controlling particulate matter by add-on control devices (fabric filters, scrubbers, etc.) and process modifications, some level of arsenic control is also achieved. Cold sources such as the cotton gins and arsenic chemical plants emit arsenic as a particulate that can be effectively controlled by the add-on devices used in these industries to meet SIP requirements.

The hot sources, including glass manufacturing and all four smelting industries, pose a somewhat different arsenic control situation because arsenic can be emitted as a vapor in these instances. Particulate controls such as fabric filters or electrostatic precipitators installed to meet SIP or NSPS emission levels are not effective on high temperature gas streams containing large amounts of vaporized arsenic. Therefore, even though a glass or smelting facility may be doing an efficient job of controlling gross particulate matter, it may be doing a poor job of reducing arsenic emissions. However, facilities that cool down the arsenic-containing gas stream prior to entering the control device have demonstrated efficient arsenic removal levels. In these instances particulate matter regulations would aid in helping to reduce atmospheric arsenic emissions.

Sulfur dioxide ($SO_2$) regulations on the State and Federal levels affect arsenic emissions from the primary copper, lead, and zinc smelting and secondary lead smelting source categories. Arsenic emissions are directly and effectively controlled through the techniques used by these four smelting industries to reduce atmospheric $SO_2$ emissions. The other source categories in this study are not regulated for $SO_2$ emissions because they either do not emit $SO_2$ or emissions of $SO_2$ are negligible in comparison to other pollutants such as particulates. The smelting source categories control $SO_2$ by the use of wet scrubbers and contact sulfuric acid plants. These types of control systems are effective on the hot exhaust gases of the smelters because they cool down the exhaust gas temperature such that vaporized arsenic losses are minimized. The arsenic components are condensed and are efficiently controlled by the devices' particulate removal mechanisms.

The arsenic emissions from a smelter process offgas stream are often well controlled if the source is complying with its applicable $SO_2$ and particulate matter regulations. However, efficient arsenic removal through $SO_2$ and particulate matter controls may not be implemented at all Arizona primary copper smelters if the currently proposed Arizona SIP for $SO_2$ is approved by EPA. The proposed Arizona SIP is not as stringent for $SO_2$ emissions as the EPA-designated, smelter-specific $SO_2$ emission limits that these smelters will otherwise have to comply with. If the proposed Arizona SIP is approved, some smelters may be able to comply with their $SO_2$ standards without applying controls equivalent to the estimated best control (EBC) technology for arsenic emissions.

The EPA NSPS limits for $SO_2$ and particulate matter from primary copper, lead, and zinc smelting and secondary lead smelting are summarized in Table 2-3.[10]

## 2.2.3 National Ambient Air Quality Standards

The requirement for the arsenic source categories to attain the national ambient air quality standards (NAAQS) for $SO_2$, particulate matter, and lead have or will have an impact on the level of arsenic emissions from the subject plants. As plants are required through SIP's to reduce $SO_2$, particulate, and lead emissions to achieve the NAAQS, some level of arsenic control will be achieved in the process. The direct effect of the NAAQS on overall arsenic emissions reduction in the seven source categories is difficult to quantify, particularly because some sources such as cotton gins, primary lead smelters, and secondary lead smelters have not yet come into full compliance with the applicable particulate (for cotton gins) and lead NAAQS's (for primary and secondary lead smelters).

The NAAQS for $SO_2$, particulate matter, and lead are summarized in Table 2-4.[11]

## 2.2.4 Worker Exposure Standards

The Occupational Safety and Health Administration (OSHA) has published concentration standards for workplace exposure to inorganic arsenic and lead that play significant roles in reducing atmospheric arsenic emissions. The OSHA standard for airborne inorganic arsenic limits in-plant worker exposure to 10 $\mu g/m^3$ averaged over any 8-hour period.[12] For lead, the exposure concentration limit for workers is 50 $\mu g/m^3$ averaged over an 8-hour period.[13] The lead standard helps reduce arsenic because the arsenic is emitted with the lead and is controlled concurrently as lead is controlled. The primary and secondary lead smelting source categories are affected by both standards. The OSHA arsenic standard applies to all other source categories except cotton ginning. Cotton ginning is excluded because it is classified as an agricultural source and agricultural sources are exempt under the regulation.[12,14]

In efforts to comply with the OSHA lead and arsenic standards, facilities have had to install control measures on both process and fugitive emission points of arsenic and lead. For the arsenic chemical manufacturing source the OSHA arsenic standard is the prime regulatory force behind the

TABLE 2-3. EPA-PROMULGATED NSPS EMISSION LEVELS FOR PARTICULATE AND SULFUR DIOXIDE[11]

| SOURCE CATEGORY | EMISSION SOURCE | POLLUTANT | EMISSION LEVEL ALLOWED, $mg/m^3$ (gr/dscf) |
|---|---|---|---|
| Primary Copper Smelting | Dryer | Particulate | 50 (0.022) |
| | Roaster, smelting furnace, converter | $SO_2$ | 0.065% |
| Primary Lead Smelting | Blast or reverb furnace, sinter machine discharge | Particulate | 50 (0.022) |
| | Sinter machine, electric smelting furnace, converter | $SO_2$ | 0.065% |
| Primary Zinc Smelting | Sinter machine | Particulate | 50 (0.022) |
| | Roaster | $SO_2$ | 0.065% |
| Secondary Lead Smelting | Blast and reverb furnaces | Particulate | 50 (0.022) |

## TABLE 2-4. NATIONAL AMBIENT AIR QUALITY STANDARDS FOR SULFUR DIOXIDE, PARTICULATE, AND LEAD

| POLLUTANT | TYPE OF STANDARD | AVERAGING TIME | FREQUENCY PARAMETER | CONCENTRATION, μg/m$^3$ (gr/dscf) |
|---|---|---|---|---|
| Sulfur oxides (as $SO_2$) | Primary | 1 yr. | Arithmetic mean | 80 (0.00004) |
| | | 24 hr. | Annual maximum[a] | 365 (0.00016) |
| | Secondary | 3 hr. | Annual maximum[a] | 1300 (0.00057) |
| Particulate | Primary | 24 hr. | Annual geometric mean | 75 (0.00003) |
| | | 24 hr. | Annual maximum[a] | 260 (0.00011) |
| | Secondary | 24 hr. | Annual geometric mean | 60 (0.00003) |
| | | 24 hr. | Annual maximum[a] | 150 (0.00007) |
| Lead | Primary | 3 months | Arithmetic mean | 1.5 (0.0000007) |
| | Secondary | 3 months | Arithmetic mean | 1.5 (0.0000007) |

[a] Not to be exceeded more than once per year.

controls applied during arsenic trioxide handling and dumping. In the glass source category the OSHA arsenic standard was the reason that a major manufacturer switched from using a dry arsenic raw material, with a large opportunity for worker exposure, to a liquid arsenic raw material with no threats to the workers from arsenic exposure. In the smelting source categories much of the problem in not being able to achieve workplace concentration limits comes from fugitive emissions. Because of the lead and arsenic standards, improvements have been made in smelter fugitive emissions control that have direct benefits towards reducing atmospheric arsenic emissions. OSHA is currently in the process of working individually with the smelting sources to control fugitive arsenic emissions that cause the 10 µg/m$^3$ standard to be violated. A similar program for lead is planned in the near future.[15]

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# 3.0 PRIMARY COPPER SMELTING

This chapter discusses the primary copper smelting industry and its associated arsenic emissions. Section 3.1 presents a brief source category description. Section 3.2 discusses the regulations currently covering the industry and the resulting level of control and associated arsenic emissions. Section 3.3 presents a discussion of the EBC options and Section 3.4 discusses the impacts of applying these options. Section 3.5 presents the input data to be used in assessing the population exposure to arsenic emissions from primary copper smelting. The ease of standards development is discussed in Section 3.6.

## 3.1 COPPER SMELTING DESCRIPTION

### 3.1.1 General Information

Metallic copper is produced from copper ore concentrates at primary copper smelters. The United States' primary copper smelting capacity totalled 1.56 million Mg (1.67 million tons) in 1979,[1] which accounted for about 70 percent of the domestic copper consumption. There are currently seven companies and 15 individual plants that produce primary copper in the U.S. Table 3-1 lists the names, locations, and production capacities of the plants. The 14 primary copper smelters exclusive of the ASARCO plant in Tacoma, Washington will be considered in this report. A separate report concerning arsenic emissions and regulatory alternatives for ASARCO-Tacoma has been published by the EPA.[2]

### 3.1.2 Process Description

The materials processed at the U.S. primary copper smelters are predominantly sulfide ore concentrates. The most common copper-bearing constituent of these ores is chalcopyrite ($CuFeS_2$). The copper content of the raw ore as mined is typically less than 1 weight percent, and flotation methods are used to produce a copper concentrate that serves as the feed to the primary smelting plant. A typical copper ore concentrate contains 15 to 30 weight percent copper and large amounts of iron, sulfur, and silicon. Other important constituents include lead, antimony, zinc, cadmium, bismuth, selenium and arsenic. Arsenic generally appears as the mineral arsenopyrite (FeAsS) in copper-bearing ores and is concentrated by the flotation process. The arsenic contents of the ore concentrates smelted at the 15 domestic copper smelters are listed in Table 3-2. The amount of arsenic in the concentrates ranges from 0.004 to 3.8 weight percent.

The copper-bearing minerals in the ore concentrate are separated from the other materials and converted to 99 percent pure "blister copper" by the

TABLE 3-1. THE DOMESTIC PRIMARY COPPER SMELTERS[2]

| PLANT | LOCATION | COPPER PRODUCTION CAPACITY[a] Mg/yr (tons/yr) |
|---|---|---|
| ASARCO/El Paso | El Paso, Texas | 104,000 (115,000) |
| ASARCO/Hayden | Hayden, Arizona | 163,000 (180,000) |
| ASARCO/Tacoma | Tacoma, Washington | 91,000 (100,000) |
| Kennecott/Hayden | Hayden, Arizona | 73,000 (80,000) |
| Kennecott/Hurley | Hurley, New Mexico | 73,000 (80,000) |
| Kennecott/McGill | McGill, Nevada | 45,000 (50,000) |
| Kennecott/Garfield | Garfield, Utah | 254,000 (280,000) |
| Phelps Dodge/Morenci | Morenci, Arizona | 161,000 (177,000) |
| Phelps Dodge/Douglas | Douglas, Arizona | 115,000 (127,000) |
| Phelps Dodge/Ajo | Ajo, Arizona | 64,000 (70,000) |
| Phelps Dodgs/Hidalgo | Hidalgo, New Mexico | 127,000 (140,000) |
| Copper Range/White Pine | White Pine, Michigan | 82,000 (90,000) |
| Magma/San Manuel | San Manuel, Arizona | 181,000 (200,000) |
| Inspiration/Miami | Miami, Arizona | 136,000 (150,000) |
| Cities Services/ Copperhill | Copperhill, Tennessee | 20,000 (22,000) |

[a] 1979 Production capacity of "blister" copper (99 percent pure copper).

TABLE 3-2. ARSENIC CONTENT OF THE FEED TO DOMESTIC COPPER SMELTERS[2]

| Plant | Arsenic content of feed[a,b] | | |
|---|---|---|---|
| | % | kg/hr | (lb/hr) |
| ASARCo-Tacoma | 3.8 | 2041 | (4500) |
| Kennecott-Garfield | 0.14 | 137 | (301) |
| Phelps Dodge-Ajo | 0.3 | 68 | (151) |
| ASARCo-El Paso | 0.22 | 60[c] | (133) |
| ASARCo-Hayden | 0.2 | 50 | (110) |
| Phelps Dodge-Hidalgo | 0.026 | 20 | (45) |
| Phelps Dodge-Douglas | 0.03 | 11 | (24) |
| Phelps Dodge-Morenci | 0.02 | 9.7[d] | (21.3) |
| Kennecott-Hayden | 0.015 | 8.5 | (18.8) |
| Kennecott-McGill | 0.03 | 7.6 | (16.7) |
| Inspiration-Miami | 0.022 | 7.6 | (16.7) |
| Magma-San Manual | 0.005 | 4.4 | (9.8) |
| Copper Range-White Pine | 0.0035 | 0.7 | (1.5) |
| Kennecott-Hurley | 0.0005 | 0.2 | (0.4) |
| Cities Service-Copperhill | 0.0004 | 0.05 | (0.1) |

[a] The feed is a mixture of concentrates, precipitates, lead smelter by-products, and smelter reverts.

[b] Does not include recycled flue dusts and other intermediates except where noted.

[c] 23 kg/hr (51 lb/hr) of this amount is fed directly to the converters.

[d] 3.4 kg/hr (7.5 lb/hr) of this amount is fed to the roaster and remaining amount is fed directly to the reverberatory furnaces.

operations at a primary copper smelter. As shown in Figure 3-1, there are three major processes involved at most smelters: roasting, smelting, and converting.

Copper ore roasting is carried out at six of the 14 smelters considered in this study. Ore concentrates generally require roasting if they are low in copper content relative to sulfur, iron, and other impurities. Roasting consists of heating the ore concentrates to about 650°C (1200°F) in an oxidizing atmosphere. The roast is carried out below the melting temperature of the charge and has three primary functions: (i) elimination of a portion of the sulfur as $SO_2$, (ii) removal of volatile impurities such as arsenic, antimony, bismuth, and cadmium, and (iii) conversion of a portion of the iron sulfides present to iron oxides. The degree of sulfur elimination accomplished in a copper roaster depends on the desired quality of the charge to the smelting furnace. The final roasted product is known as the calcine.

There are two types of roasters used in the domestic copper smelting industry, multiple hearth roasters and fluid bed roasters. Of these two types, fluid bed roasters represent a more recent design. For a given degree of sulfur removal, they require a shorter concentrate residence time and produce a higher strength $SO_2$ offgas stream than do multiple hearth roasters. Three of the six smelters that roast ore concentrates use multiple hearth roasters and three use fluid bed roasters.

The emission control technologies that can be applied to the two types of roasters depend on the $SO_2$ content of the offgas streams. The $SO_2$ content of multiple hearth roaster offgas is too low for economical treatment with a contact sulfuric acid plant unless the stream can be blended with a more concentrated $SO_2$ stream. Two of the three plants currently using multiple hearth roasters have no $SO_2$ control on the roaster offgas. Electrostatic precipitators (ESP's) are employed for particulate control. The third plant using a multiple hearth roaster (ASARCO/El Paso) employs offgas blending with a lead sinter machine offgas to produce a sufficient concentration of $SO_2$ to treat with a contact sulfuric acid plant. All three existing fluid bed roasters in operation currently use contact sulfuric acid plants to control roaster $SO_2$ emissions.

The second step in the production of metallic copper from copper-bearing ore is the smelting process. The feed to the smelting furnace consists of either hot calcine from the roaster or unroasted ore concentrates ("green charge") along with siliceous or limestone flux. These materials are melted in the furnace at a temperature of about 1500°C (2730°F). In the molten state, several complex metallurgical reactions occur in which copper and higher iron oxides are chemically reduced, and sulfur is liberated as $SO_2$. The smelting furnace operations results in the production of two distinct phases: a copper-rich phase known as the matte that consists primarily of iron sulfide and copper sulfide, and a copper-lean phase known as the slag that can be ideally represented by the

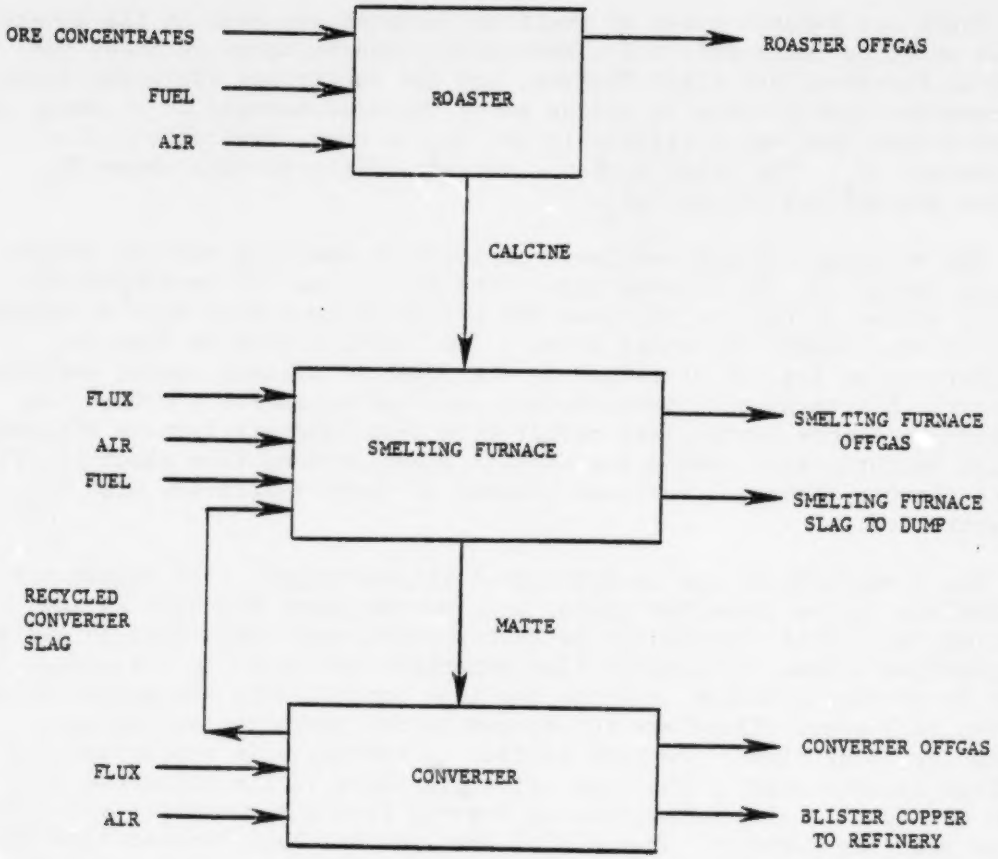
ORE CONCENTRATES
FUEL
AIR
ROASTER
ROASTER OFFGAS
CALCINE
FLUX
AIR
FUEL
SMELTING FURNACE
SMELTING FURNACE OFFGAS
SMELTING FURNACE SLAG TO DUMP
RECYCLED CONVERTER SLAG
MATTE
FLUX
AIR
CONVERTER
CONVERTER OFFGAS
BLISTER COPPER TO REFINERY

Figure 3-1. Schematic diagram of a primary copper smelter.

formula 2FeO + $SiO_2$. The slag and matte phases separate within the furnace by virtue of their mutual insolubility, and the slag layer floats above the matte. The two phases are tapped from the furnace separately. The furnace slag is discarded due to its low copper content and the copper-bearing matte is sent to the converter for further processing. The net result of the smelting step is the separation of the copper-containing portion of the furnace charge from the non-copper containing portion.

There are several types of smelting furnaces employed in the domestic copper smelting industry: the conventional reverberatory furnace, the electric furnaces, the flash furnace, and the continuous (Noranda) furnace. The reverberatory furnace is unique among the list because it produces an offgas stream that has a relatively low $SO_2$ content, typically 0.5 to 1.5 percent $SO_2$. The other furnaces produce offgas streams whose $SO_2$ content exceeds 3.5 percent $SO_2$.

The existing control equipment employed on smelting furnace offgas streams depends on the furnace type. The $SO_2$ content of reverberatory furnace offgas is too low to treat the stream economically with a contact sulfuric acid plant, and other forms of $SO_2$ control such as flue gas desulfurization are not practiced in the domestic primary copper smelting industry. Electrostatic precipitators are used exclusively within the industry to remove particulate matter from reverberatory furnace offgases. Contact sulfuric acid plants are used to treat streams from electric, flash, and continuous (Noranda) furnaces because of their relatively high $SO_2$ concentration.

The final step in the production of blister copper from copper ore concentrate is the converter operation. Molten matte produced in the smelting furnace is transferred to Pierce-Smith type converters in ladles via overhead cranes. Siliceous flux materials are added to the charge in order to provide a medium in which the iron contained in the matte can be removed as a slag. There are two stages in the converter operations. During the "slag blow", the iron sulfide in the matte is preferentially oxidized to iron oxide. The iron oxide dissolves in the siliceous flux phase and forms a slag layer that is removed from the converter and recycled to the smelting furnace. When all of the iron has been removed from the converter charge in this manner, molten copper sulfide is converted to metallic blister copper and sulfur dioxide during the "copper blow", which is represented by the following reaction:

$$Cu_2S + O_2 \rightarrow 2Cu + SO_2$$

The unique feature of the converter operation is that it is a batch process occurring in discrete modes. The characteristics of the converter offgas vary during the different modes. The $SO_2$ content of the offgas stream is higher during the copper blow than during the slag blow.

Offgases from the converter operation that are captured by the primary converter hooding system are treated in contact sulfuric acid plants at 11 of the 14 copper smelters considered in this study. Of the remaining three plants, two use hot electrostatic precipitator systems (Kennecott/McGill and Phelps Dodge/Douglas) for particulate control and one (Copper Range/White Pines) has no converter offgas pollution control equipment.

The 99 percent pure blister copper produced by the converter is subsequently refined to reduce the level of various impurities. Virtually all copper produced by matte smelting is fire refined in rotary-type refining furnaces or in small hearth furnaces. Copper refining consists of a series of operations in which the blister copper is first oxidized to $Cu_2O$ and then reduced back to metallic copper.

### 3.1.3 Arsenic Emissions from Primary Copper Smelters

Less than 5 percent of the arsenic input to a primary copper smelter typically remains in the blister copper product. The two mechanisms of arsenic removal from the copper-bearing material are volatilization and slagging. Arsenic is volatilized primarily as arsenic trioxide ($As_2O_3$) in the roaster, the smelting furnace, and the converter. Slagging of arsenic in the form of metallic arsenates such as iron arsenate [$Fe_3\ (AsO_4)_2$] occurs from the smelting furnace and the converter. The distribution of arsenic among the offgas and slag streams varies considerably among smelters, but some general conclusions can be drawn regarding the magnitude of arsenic removal from each of the various process and fugitive sources as discussed below.

3.1.3.1 Process Arsenic Emissions. The three major sources of process arsenic emissions are the roaster, the smelting furnace, and the converter. The magnitude of the arsenic emissions from each of these process emission sources is considered below. A detailed discussion of this topic can be found in a paper by Weisenberg, Bakshi, and Vervaert.[3]

The fraction of arsenic in the ore concentrate that is volatilized in the roaster may vary from as little as 4 percent to as much as 90 percent, with 25 percent being a typical value. The fractional volatilization depends on several variables including temperature, residence time, arsenic content of the ore concentrate, and the oxidizing/reducing atmosphere within the roaster. These operating variables are indirectly determined by the desired grade (copper to sulfur ratio) of the matte that will ultimately be sent to the converter. In general, volatilization of arsenic as arsenic trioxide ($As_2O_3$) is enhanced by relatively low roasting temperatures and mild oxidizing conditions. High temperature, strong oxidizing roaster conditions can cause the formation of the less volatile arsenic pentoxide ($As_2O_5$) that interacts with available metal oxides such as iron oxide (FeO) to form stable, non-volatile arsenates that remain in the calcine.

Multiple hearth roasters tend to eliminate more arsenic by volatilization than do fluid bed roasters, although the difference between the two roaster types is not substantial. It has been theorized that the difference may be due to the local variability of conditions within a multiple hearth roaster, which is assumed to give rise to areas within the roaster that are favorable to arsenic volatilization. The increased residence time of the ore concentrate in a multiple hearth roaster as compared to a fluid bed roaster may also be a contributing factor to the enhanced arsenic volatilization.

The relative amounts of arsenic volatilized and slagged in the smelting furnace depends mainly on the furnace type and on the arsenic content of the furnace feed material. Weisenberg, et al.[3] made the following observations concerning arsenic elimination from reverberatory furnaces based on the arsenic content of the ore concentrate entering the smelter complex:

1. With high arsenic feed (> 0.2 percent), 55-75 percent of the arsenic entering the reverberatory furnace leaves in the gas phase and 10-25 percent is slagged out.

2. With low arsenic feed (< 0.2 percent), 5-37 percent of the arsenic entering the reverberatory furnace leaves in the gas phase and 16-55 percent is slagged out.

The behavior of arsenic in an electric smelting furnace is reported to be similar to that in the reverberatory furnace. The arsenic volatilization from a flash furnace is approximately 76-85 percent of the arsenic in the furnace feed while the amount slagged varies from about 7-17 percent of the furnace feed.

Arsenic removal in the converter is dependent on the matte grade of the furnace product. Low grade mattes (low copper to sulfur ratio) tend to result in greater fractional arsenic volatilization than do high grade mattes. This is believed to be due to the combination of the early appearance of metallic copper in the converting of high grade matte and the fact that arsenic is thermodynamically more stable in copper than in copper sulfide. In normal practice approximately 70 percent of the arsenic entering the converter is volatilized and about 16 percent is left in the converter slag that is subsequently recycled to the smelting furnace.

The EPA has developed arsenic material balance data for all 14 copper smelters contained in this study.[2] The total fraction of arsenic entering with the smelter feed that is volatilized in the smelters ranges from about 40 percent to nearly 100 percent.

3.1.3.2 Fugitive Arsenic Emissions. Fugitive arsenic emissions from primary copper smelters are described in detail in reference 2. Based on measurements made at ASARCO/Tacoma, the magnitude of the uncontrolled fugitive arsenic emissions is estimated to be about 2.4 percent of the arsenic entering with the smelter feed. Table 3-3 lists the approximate distribution of fugitive arsenic emissions among the seven largest fugitive sources. Greater than 90 percent of the total fugitive arsenic emissions are associated with the converter operations (about 76 percent) and the smelting furnace matte and slag tapping operations (about 15 percent).

## 3.2 INORGANIC ARSENIC EMISSIONS UNDER EXISTING REGULATIONS

### 3.2.1 Regulatory Impacts

The emission control systems currently in place in the primary copper smelting industry are summarized in Table 3-4. Improved emission controls will be required at several smelters in order to achieve compliance with the regulatory baseline $SO_2$ and particulate regulations. Varying degrees of arsenic control are achieved by the requirements to comply with these baseline limitations. The estimated impacts of existing regulations on the copper smelting industry are discussed below.

Primary copper smelters are currently regulated by particulate and $SO_2$ SIP emission standards as well as NSPS for particulate and $SO_2$. These baseline regulations have motivated a considerable amount of retrofit and redesign activity within the primary copper smelting industry. Most of the proposed and completed plant changes have been aimed at the reduction of stack $SO_2$ emissions by the introduction of smelting furnace process changes and the installation of add-on pollution control equipment. In general, the $SO_2$ standards have caused the industry to shift towards smelting technologies that produce offgas streams of sufficiently high $SO_2$ concentration to be treated economically in contact sulfuric acid plants for sulfur removal.

The impact of the regulatory baseline is expected to affect the level of copper roaster arsenic control currently in place at two of the six copper smelters using roasters: the ASARCO/Hayden and Phelps Dodge/Douglas smelters. The need for the multiple hearth roaster at ASARCO/Hayden will be eliminated when a new flash smelting furnace controlled by a contact sulfuric acid plant is installed to replace the existing reverberatory smelting furnace. The Phelps Dodge/Douglas smelter has not announced plans for achieving regulatory baseline compliance and is expected to close down in the future. The remaining four copper smelters using roasters (ASARCO/El Paso, Kennecott/Hayden, Phelps Dodge/Morenci, and Cities Services/Copperhill) will be able to achieve regulatory baseline compliance without changing their roaster emission control systems.

The largest impact of the regulatory baseline will be on the smelting furnace operations. At least four copper smelters (ASARCO/Hayden, Kennecott/Hurley, Phelps Dodge/Morenci, and Phelps Dodge/Ajo) have announced plans to modify or replace their existing reverberatory furnaces so that they can install acid plant units for furnace offgas $SO_2$ control and achieve compliance with the regulatory baseline. Two Arizona smelters

## TABLE 3-3. DISTRIBUTION OF UNCONTROLLED FUGITIVE ARSENIC EMISSIONS AT A PRIMARY COPPER SMELTER[a]

| FUGITIVE EMISSION SOURCE | ESTIMATED UNCONTROLLED FUGITIVE ARSENIC EMISSIONS (as % of arsenic input in smelter feed) | ESTIMATED UNCONTROLLED FUGITIVE ARSENIC EMISSIONS (as % of total uncontrolled fugitive arsenic emissions) |
|---|---|---|
| 1. Calcine transfer | 0.02 | 1.0 |
| 2. Matte tap | 0.34 | 14.0 |
| 3. Slag tap | 0.01 | 0.5 |
| 4. Converter operations | 1.83 | 76.3 |
| 5. Anode furnace | 0.11 | 4.7 |
| 6. Flue dust handling | 0.09 | 3.7 |
| 7. Slag dumping | Unknown | Unknown |
| TOTAL | 2.4% | 100% |

[a] Based on estimates at ASARCO/Tacoma, exclusive of fugitive emissions from the arsenic building. (See Reference 2.)

## TABLE 3-4 SUMMARY OF THE EXISTING EMISSION CONTROL SYSTEMS CURRENTLY IN PLACE IN THE PRIMARY COPPER SMELTING INDUSTRY

| ROASTER | SMELTING FURNACE | CONVERTER |
|---|---|---|
| Multiple Hearth Roasters (3) | Reverberatory Furnaces (10) | Pierce-Smith Converters (14) |
| = "hot" ESP systems (2) (30 to 75 percent arsenic removal) | - "hot" ESP systems (9) (30 to 75 percent arsenic removal) | = primary hooding over converter mouth (14) |
|  |  | PLUS: |
| = contact sulfuric acid plant treating blended offgas stream (1) (98 to 99 percent efficiency) | - "cold" ESP systems (1) (spray chamber/ESP, 96 percent arsenic removal | = contact sulfuric acid plant with auxiliary equipment (98 to 99 percent arsenic removal) (11) |
| Fluidized Bed Roasters (3) | Electric, Flash, Noranda Furnaces (4) | = "hot" ESP systems (2) (30 to 75 percent arsenic removal) |
| = contact sulfuric acid plant with auxiliary pre-cleaning equipment (3) (98 to 99 percent efficiency) | - contact sulfuric acid plant with auxiliary equipment (4) (98 to 99 percent arsenic removal) | = no control (1) |
| No Roaster (8) |  |  |
| Multiple Hearth Roasters | All types of furnaces require similar fugitive controls, existing plants have some or all of the following: | Pierce - Smith Converters |
| = local hooding around calcine discharge area vent to<br>= baghouse<br>= ESP | Matte tapping:<br>- local tap port exhaust hoods<br>- matte launder hoods<br>- retractable ladle hoods | = fixed-type or retractable secondary hooding exists at four plants<br>= building evacuation is applied at one plant |
| Fluidized Bed Roasters | Slag Tapping:<br>- local tap port exhaust hoods<br>- slag launder hoods |  |
| = no extra fugitive controls necessary |  |  |

[a] Does not include ASARCO/Tacoma.

(Kennecott/Hayden and Magma/San Manual) are awaiting approval of the proposed Arizona SIP for $SO_2$ emissions before announcing compliance plans. If the Arizona SIP is approved, the Kennecott/Hayden smelter will most likely be able to achieve regulatory baseline compliance without making changes in either its smelting furnace or its smelting furnace emission control system. The Magma/San Manual smelter will most likely require a partial $SO_2$ scrubbing system on its reverberatory furnace offgases to achieve compliance under the Arizona SIP approval regulatory scenario.[6] If the Arizona SIP is not approved, the Kennecott/Hayden and Magma/San Manual smelters will be required to comply with a set of EPA-promulgated $SO_2$ emission limitations. Under these EPA $SO_2$ limits, major furnace modifications and acid plant installations at Kennecott/Hayden and Magma/San Manual would probably be required to achieve compliance. The Phelps Dodge/Douglas and Kennecott/McGill smelters have not announced plans for achieving regulatory baseline compliance and are expected to shut down their smelting furnace operations in the future. The remaining six smelters (ASARCO/El Paso, Kennecott/Garfield, Phelps Dodge/Hidalgo, Copper Range/White Pines, Inspiration/Miami, and Cities Services/Copperhill) will achieve regulatory compliance without changes in their smelting furnace or smelting furnace control systems.

The impact of the regulatory baseline will not affect the level of copper converter arsenic control at the 11 copper smelters using contact sulfuric acid plants to reduce converter $SO_2$ emissions. Of the remaining three copper smelters considered in this study, the Copper Range/White Pines smelter will be able to achieve regulatory compliance without adding any converter emission controls, and the Phelps Dodge/Douglas and Kennecott/McGill smelters are expected to shut down operations.

The primary copper smelters are also required to comply with the Occupational Safety and Health Administration (OSHA) workplace inorganic arsenic standard. Agreements are currently being reached between OSHA and five individual smelters that will result in improvements in fugitive emission control systems at these smelters.[4]

Table 3-5 summarizes the process and fugitive emission control systems that are expected to be in place under compliance with all existing regulations. The assumption has been made that the Arizona SIP will be approved and that Kennecott/Hayden and Magma/San Manual will not require furnace modifications to achieve regulatory baseline compliance.

### 3.2.2 Arsenic Removal Capabilities of Existing Control Equipment

The effectiveness of available process and fugitive emission control systems in controlling arsenic emissions are discussed in the following sections.

3.2.2.1 Process Emission Controls. The process emission control systems used in the primary copper smelting industry include baghouses,

## TABLE 3-5. EXPECTED BASELINE COPPER SMELTER CONFIGURATIONS AND EMISSION CONTROL SYSTEMS
(Based on SIP Approval Regulatory Scenario)

| Plant | Blister Copper Capacity (Mg/yr) | Plant Components | Process Emission Controls | Fugitive Emission Controls |
|---|---|---|---|---|
| ASARCo/El Paso | 104,000 | MHR<br>REV<br>3 CONV | AP<br>SC/ESP<br>AP | Ventilation → ESP<br>Ventilation → FF → ESP<br>A.C./2° Hood[b] + Building Evac → FF |
| ASARCo/Hayden | 163,000 | FLASH[a]<br>5 CONV | AP[a]<br>AP | Ventilation Only<br>Fixed 2° Hood Only |
| Kennecott/Hayden | 73,000 | FBR<br>REV<br>3 CONV | AP<br>ESP<br>AP | NA<br>Ventilation Only<br>No Capture or Control |
| Kennecott/Hurley | 73,000 | FLASH[a]<br>4 CONV | AP[a]<br>AP | Ventilation Only[b]<br>No Capture or Control |
| Kennecott/McGill[c] | 45,000 | REV<br>2[b] CONV | ESP<br>ESP | No Capture or Control<br>No Capture or Control |
| Kennecott/Garfield | 254,000 | NOR<br>4 CONV | AP<br>AP | Ventilation<br>Ventilation |
| Phelps Dodge/Morenci | 161,000 | FBR<br>Modified REV[a]<br>7 CONV | AP<br>AP[b]<br>AP | NA<br>Ventilation Only<br>Fixed 2° Hood Only |
| Phelps Dodge/Douglas[c] | 115,000 | MHR<br>REV<br>5 CONV | ESP<br>ESP<br>ESP | Ventilation → FF<br>Ventilation → ESP<br>No Capture or Control |

TABLE 3-5. Continued.

| Plant | Blister Copper Capacity (Mg/yr) | Plant Components | Process Emission Controls | Fugitive Emission Controls |
|---|---|---|---|---|
| Phelps Dodge/Ajo | 64,000 | Modified REV[a]<br>3 CONV | AP[a]<br>AP | Ventilation Only<br>Fixed 2° Hood Only |
| Phelps Dodge/Hidalgo | 127,000 | FLASH<br>2 CONV | AP<br>AP | Ventilation Only[b]<br>Fixed 2° Hood Only |
| Copper Range/White Pines | 82,000 | REV<br>2 CONV | ESP<br>None[d] | Ventilation Only[b]<br>No Capture or Control[b] |
| Magma/San Manual | 181,000 | REV<br>2 CONV | ESP, Partial SCR[a]<br>AP | Ventilation Only<br>No Capture or Control |
| Inspiration/Miami | 136,000 | EF<br>5 CONV | AP<br>AP | Ventilation Only<br>No Capture or Control |
| Cities Services/ Copperhill | 20,000 | FBR<br>EF<br>2 CONV | AP<br>AP<br>AP | NA<br>Ventilation Only[b]<br>No Capture or Control |

[a] Equipment indicated is not currently in place but would most likely be sufficient to insure compliance with existing regulations.

[b] Assumed status of control based on common smelter practice.

[c] Kennecott/McGill and Phelps Dodge/Douglas are expected to close due to non-compliance with existing regulations.

[d] An acid plant is not needed for converter emissions at the White Pines smelter to achieve regulatory compliance because of the low sulfur content of the ore smelted.

Abbreviations:
MHR = multiple hearth roaster
FBR = fluid bed roaster
REV = reverberatory smelting furnace
FLASH = flash smelting furnace
NOR = noranda smelting furnace
NA = not applicable
CONV = Pierce-Smith Converter
AP = contact sulfuric acid plant
SC = spray chamber
ESP = electrostatic precipitator
FF = fabric filter
SCR = $SO_2$ scrubbing system
A.C./2° = air curtain/secondary

electrostatic precipitators, venturi scrubbers, contact sulfuric acid plants, and auxiliary spray chamber/gas cooling systems. Although not specifically designed for arsenic removal, the existing pollution control devices at the domestic primary copper smelters achieve various degrees of arsenic emissions control. The EPA has conducted a test program aimed at quantifying the arsenic removal efficiencies of existing equipment at several copper smelters. Arsenic removal efficiency tests have been conducted on portions of the process emissions control systems at the ASARCO/El Paso, ASARCO/Tacoma, Kennecott/Hayden, Phelps Dodge/Ajo and Anaconda/Anaconda (now closed) primary copper smelters. The arsenic removal efficiencies of existing baghouses, electrostatic precipitators, venturi scrubbers, and contact sulfuric acid plant/gas precleaning systems were evaluated at these facilities. The inlet temperatures to the emission control systems tested ranged from 80 to 350°C (175 to 660°F), and the inlet loading of arsenic ranged from 0.07 to 885 $mg/Nm^3$. A systematic effort to separate the effects of varying temperature and inlet arsenic loading on the performance of the systems was not undertaken. The conclusion of the test work was that baghouses, ESPs, and venturi scrubbers have essentially equivalent performance capabilities for the collection of arsenic (96 to 99 percent collection efficiency) when each of the devices is operated at temperatures below 115°C. The arsenic collection efficiency recorded for a double contact sulfuric acid plant system at ASARCO/El Paso treating a relatively concentrated arsenic stream (252 $mg/Nm^3$) was found to be greater than 99 percent. The extensive precleaning system associated with an acid plant, which consists of a hot ESP in series with an impingement-type scrubber, a cold ESP, and occassionally a venturi-type scrubber, is largely responsible for the effectiveness of these systems in removing arsenic. In other tests, a single contact acid plant at the Phelps Dodge/Ajo copper smelter treating an extremely dilute arsenic stream (0.07 $mg/Nm^3$) had an average arsenic removal efficiency of 75 percent. Although the removal efficiency of 75 percent for the single contact acid plant system is low compared to the test results for the other devices, the stream being treated had an inlet arsenic concentration more than two orders of magnitude less than in any of the other tests. Since single and double contact acid plants require the same level of gas precleaning it is assumed that they have comparable arsenic removal capabilities when treating offgas streams of comparable inlet arsenic loading.

The EPA has demonstrated the importance of gas temperature in controlling arsenic emissions from copper smelters. An analysis of the temperature effects on arsenic emissions control is presented in Chapter 2. Test results at Phelps Dodge/Ajo show that an ESP operating at elevated temperatures (above 315°C in the test case) can have good particulate removal efficiency (96.7 percent based on in-stack measurements) but poor arsenic removal efficiency (27.8 percent based on out of stack measurements). Due to the volatile nature of arsenic trioxide, significant amounts of arsenic can pass through a particulate control device in the vapor phase if the device is operated at a sufficiently high temperature. From the standpoint of arsenic emission control, offgas temperatures should be reduced as low as is feasible prior to entering a particulate control device in order to minimize the amount of arsenic escaping in the vapor phase. A lower bound on the feasible offgas temperature reduction is imposed by the acid dew point of the gas stream. Although the $SO_3$ content of a smelter offgas stream is fairly low, dilute $SO_3/H_2O$ vapor phase mixtures condense to much stronger sulfuric acid mixtures in the liquid phase. This situation can cause corrosion problems if the acid is allowed to condense onto the particulate control device. Thus, the recommended operating temperature of a dry control device such as a baghouse or ESP is 10° to 25°C above the acid dew point of the gas stream being treated. Although the acid dew points of smelter offgas streams are expected to vary considerably, practical experience at two smelters (Anaconda and ASARCO/El Paso) have led EPA to recommend an operational temperature of 110°C (230°F) as within tolerable limits. Gas cooling is commonly provided by one of three methods: spray chamber/evaporative cooling, dilution air cooling, and convective/radiative cooling.

3.2.2.2 Fugitive Emission Controls. In general, fugitive emission control systems consist of ventilation followed by particulate control. The overall efficiency of the fugitive control systems is the product of the ventilation capture efficiency and the particulate collection efficiency. At present the overall efficiency of fugitive emission control systems in the primary copper smelting industry is limited primarily by the capture efficiency of the ventilation systems. In the case of converter fugitive controls, the effectiveness of the fixed converter secondary hood systems in place at domestic copper smelters was judged to be low. The best ventilation capture efficiencies achievable for converter fugitives is about 90-95 percent using the air curtain/secondary hood technology developed in Japan. Reference 2 contains a complete discussion of the test work that has been done to quantify the effectiveness of copper smelter fugitive emission controls in reducing fugitive arsenic emissions.

### 3.2.3 Inorganic Arsenic Emissions Under the Regulatory Baseline

The estimated baseline inorganic arsenic emissions of the copper smelters considered in this study are shown in Table 3-6. The emissions estimates range from 0.0045 to 5.2 kg/hr (0.01 to 11.5 lb/hr). The methods used to obtain the estimates are detailed in Appendix A-3.

## 3.3 ARSENIC EBC OPTIONS FOR THE PRIMARY COPPER SMELTING INDUSTRY

### 3.3.1 EBC Option Selection

Table 3-7 summarizes the EBC options for arsenic emissions from the primary copper smelting industry. The EBC options for both process and fugitive arsenic emission control systems were selected based on the test work discussed in Section 3.2.2 and on the feasibility of the controls as demonstrated at existing domestic and/or foreign facilities.

## TABLE 3-6. ESTIMATED TOTAL BASELINE INORGANIC ARSENIC EMISSIONS FROM THE PRIMARY COPPER SMELTERS

| PLANT | TOTAL BASELINE ARSENIC EMISSIONS kg/hr | (lb/hr) |
|---|---|---|
| ASARCO/El Paso | 2.9 | (6.4) |
| ASARCO/Hayden | 3.1 | (6.8) |
| Kennecott/Hayden | 4.4 | (9.7) |
| Kennecott/Hurley | 0.0045 | (0.10) |
| Kennecott/McGill | 2.0 | (4.4) |
| Kennecott/Garfield | 2.0 | (4.4) |
| Phelps Dodge/Morenci | 0.89 | (2.0) |
| Phelps Dodge/Douglas | 0.96 | (2.1) |
| Phelps Dodge/Ajo | 5.2 | (11.5) |
| Phelps Dodge/Hidalgo | 0.53 | (1.2) |
| Copper Range/White Pine | 0.45 | (0.99) |
| Magma/San Manuel | 3.1 | (6.8) |
| Inspiration/Miami | 1.0 | (2.2) |
| Cities Services/Copperhill | 0.011 | (0.024) |

TABLE 3-7. EBC OPTIONS FOR PRIMARY COPPER SMELTERS

| ROASTER | SMELTING FURNACE | CONVERTER |
|---|---|---|
| Multiple Hearth Roasters<br>- options:<br>(1) "cold" FF or ESP system (e.g., spray chamber/FF or/ESP capable of cooling to 110°C.)<br>(2) combine low-$SO_2$-strength roaster offgases with high-$SO_2$-strength converter offgases and send to contact acid plant system<br>Fluid Bed Roaster<br>- contact sulfuric acid plant with auxiliary gas pre-cleaning system | Reverberatory Furnaces<br>- options:<br>(1) "cold" FF or ESP system (e.g., spray chamber/FF or/ESP capable of cooling to 110°C.)<br>(2) combine low-$SO_2$-strength reverb offgases with high-$SO_2$-strength converter offgases and send to contact acid plant system (not demonstrated)<br>(3) FGD system (very costly)<br>Electric, Flash, and Noranda Furnaces<br>- contact sulfuric acid plant with auxiliary gas pre-cleaning system | Pierce-Smith Converter<br>- primary hooding over converter mouth PLUS:<br>- contact sulfuric acid plant with auxiliary gas pre-cleaning system |
| Multiple Hearth Roaster<br>- fully enclosed calcine hopper area with adequate ventilation, vented to fabric filter or ESP<br>Fluid Bed Roaster<br>- no additional controls required | All furnace types:<br>- for both matter and slag tapping, all of the following:<br>- local tap port exhaust hoods<br>- launder hoods or fully enclosed launder<br>- retractable ladle hoods<br>- vent to FF or ESP | Pierce-Smith Converter<br>- options:<br>(1) secondary hooding, preferrably of mechanical type with FF or ESP<br>(2) air curtain along with secondary hooding system with FF or ESP<br>(3) building evacuation fugitive emissions capture system with FF or ESP |

#### 3.3.1.1 Process Emissions EBC Options.

Contact sulfuric acid plants are recommended as arsenic EBC for any copper smelter offgas stream with a $SO_2$ concentration of 3.5 percent or more. Acid plants have been demonstrated as feasible for treating fluid bed roaster offgases; electric, flash, and Noranda smelting furnace offgases; and converter process offgases.

Baghouse or ESP systems operated at 110°C (230°F) or below are recommended as arsenic EBC for primary offgas streams with low $SO_2$ content. Available information supports the feasibility of operating the baghouse or ESP unit at about 110°C (230°F) with no deleterious effects due to corrosion.

#### 3.3.1.2 Fugitive Emissions EBC.

Fugitive arsenic emission EBC consists of local ventilation appropriate to the source under consideration followed by particulate collection in a fabric filter or ESP system. The air curtain/secondary hood system listed in Table 3-7 as an EBC option for converter fugitives has not been demonstrated in the domestic primary copper smelting industry although it has been demonstrated in Japan.

### 3.3.2 Prevalance of Arsenic EBC Under Existing and Baseline Levels of Control

#### 3.3.2.1 Process Emission Controls.

Table 3-8 shows the status of the existing and baseline process emissions control systems in comparison to arsenic EBC for each of the domestic primary copper smelters considered in this study. At the level of control currently found in the industry only five of the 14 smelters have arsenic EBC in place for each of the three main sources of arsenic process emissions (roaster, smelting furnace, converter).

The emission control changes that will be made to achieve compliance with $SO_2$ emission limitations will result in the application of arsenic EBC for process emissions at several additional smelters. Two baseline scenarios are shown that indicate which copper smelters are expected to be controlled at the arsenic EBC level as a result of their efforts to comply with $SO_2$ regulations. Under the scenario that will result if the proposed SIP $SO_2$ limits are approved, at least nine of the 14 copper smelters will be controlled at the EBC level for arsenic process emissions once $SO_2$ compliance is achieved. Of the remaining five smelters, Phelps Dodge/Douglas and Kennecott/McGill are considered likely to shut down operations as a result of their inability to meet $SO_2$ emission limitations. Three smelters: Kennecott/Hayden, Magma/San Manual, and White Pines/Michigan, are not likely to be at EBC for arsenic process emissions when complying with the regulatory baseline.

Under the scenario that will result if the more stringent EPA-promulgated $SO_2$ limits are applied to the copper smelters, 11 of the 14 smelters will be controlled at the arsenic EBC level upon achieving $SO_2$ compliance. Of the remaining three, Phelps Dodge/Douglas and

## TABLE 3-8. PREVALENCE OF ARSENIC EBC FOR PROCESS EMISSIONS UNDER EXISTING AND BASELINE CONTROL LEVELS[6,7,8]

| | EXISTING CONTROL | BASELINE CONTROL | | |
|---|---|---|---|---|
| PLANT | CONFIGURATION AS FOUND | LIKELY CONFIG. REQUIRED BY SIP $SO_2$ LIMITS | LIKELY CONFIG. REQUIRED BY EPA $SO_2$ LIMITS | COMMENTS |
| ASARCO/<br>El Paso, TX | YES | YES | YES | Changes in reverb furnace offgas $SO_2$ control possible but not required. |
| Cities Services/<br>Copperhill, TN | YES | YES | YES | No changes anticipated. |
| Inspiration/<br>Miami, AZ | YES | YES | YES | No changes anticipated except for improvement of converter fugitive controls. |
| Kennecott/<br>UT | YES | YES | YES | No changes anticipated. |
| Phelps Dodge/<br>Hidalgo, NM | YES | YES | YES | No changes anticipated. |
| ASARCO/<br>Hayden, AZ | NO | YES | YES | May shut down roaster and install flash furnace/AP to replace reverb. |
| Kennecott/<br>Hurley, NM | NO | YES | YES | Inco flash furnace/AP to be installed. |
| Phelps Dodge/<br>Morenci, AZ | NO | YES | YES | Retrofit of existing reverb furnace planned using oxy-fuel or oxy-concentrate burners. Acid plant to be installed. |
| Phelps Dodge/<br>Ajo, AZ | NO | YES | YES | Retrofit of existing reverb furnace planned using oxy-guel or oxy-concentrate burners. Acid plant to be installed. |
| Kennecott/<br>Hayden, AZ | NO | NO | YES | No change under proposed Arizona SIP. Reverb offgas scrubbing or flash furnace/AP installation required under EPA limits. |
| Magma/<br>San Manuel, AZ | NO | NO | YES | Partial scrubbing under proposed Arizona SIP. Total scrubbing or flash furnace/AP under EPA limits. |
| Phelps Dodge/<br>Douglas, AZ | NO | ? | ? | Smelter expects to apply for Non-ferrous Smelter Order (NSO) with waiver; shutdown expected upon expiration of NSO. |
| Kennecott/<br>McGill, NV | NO | ? | ? | No announced plan. May control converter offgases after Nevada SIP revision approved. |
| Copper Range/<br>White Pine, MI | NO | NO | NO | No changes anticipated. |

Kennecott/McGill would be expected to shut down their operations, while the White Pines smelter would achieve $SO_2$ compliance without the application of arsenic EBC.

On the basis of the above discussion, at most three of the smelters that are expected to continue operating will not be controlled at the EBC level for process arsenic emissions upon achieving compliance with the regulatory baseline. These smelters are: Kennecott/Hayden, Magma/San Manuel, and White Pines/Michigan. To reach arsenic EBC for process emissions each of the three smelters requires a spray chamber/gas cooling system to lower the operating temperature of existing electrostatic precipitator units and thereby reduce arsenic trioxide vapor losses.

3.3.2.2 Fugitive Emission Controls. Fugitive arsenic emissions EBC from both the furnace tapping and converter operations currently are not in place at any of the domestic primary copper smelters. Although adequate local ventilation is generally in place for furnace tapping operations, most smelters (with the exception of ASARCO/El Paso) vent the captured furnace fugitives uncontrolled to the atmosphere. Converter fugitive controls are not well developed in the domestic primary copper smelting industry. The existing secondary hood and building evacuation systems currently in place do not meet the level of arsenic control demonstrated by the best foreign converter fugitive control systems.

The fugitive emission control changes that will be made at the domestic primary copper smelters due to OSHA arsenic regulations will result in the installation of arsenic EBC at just one smelter (ASARCO/El Paso). The OSHA/industry agreements call for the implementation of a push-pull air curtain system for converter fugitive control at the ASARCO/El Paso plant provided that the technology is successfully demonstrated at ASARCO/Tacoma, where a test system of this type is now in place.[5] This development will leave ASARCO/El Paso at EBC for the two largest sources of inorganic arsenic emissions, the furnace tapping and converter operations. All of the other plants considered in this study will lack both an arsenic removal device for the collection of ventilation-captured fugitive arsenic emissions from the smelting furnace as well as an EBC system for converter fugitive emissions.

## 3.4 INCREMENTAL IMPACT OF EBC OPTIONS

The impact of the arsenic EBC options on the primary copper smelting industry has been assessed for each of the 14 smelters considered in this study. The impact analysis is based on the information presented in Table 3-5, which summarizes the most likely baseline process configuration and pollution control systems for each of the plants. The table is based on the assumption that the copper smelters will achieve compliance with the baseline $SO_2$ and particulate regulations as defined by their respective SIP's. Incremental environmental, energy, and economic impacts associated with the implementaion of EBC for the control of arsenic emissions from the primary copper smelters will be discussed in the following sections.

### 3.4.1 Environmental Impacts

By far the greatest environmental impact associated with the implementation of arsenic EBC in the primary copper smelting industry would be the reduction of atmospheric arsenic emissions. Table 3-9 includes the achievable incremental arsenic emission reductions at each plant under EBC control. It is estimated that the total arsenic emissions reduction achievable for the entire primary copper smelting industry is about 114 Mg/yr (126 tons/yr) below the emissions level associated with the regulatory baseline. The methods used to obtain the emissions reduction estimates are presented in Appendix A-3.

The water and solid waste impacts associated with implementing arsenic EBC are minimal. No additional wastewater would be generated by the new spray chamber units operated at the three smelters requiring improved process arsenic emission controls. All cooling water would be evaporated in the spray chamber, leaving only a mud-like residue. This mud is then periodically disposed of in a secured landfill along with other smelter slags that cannot be recycled. From the standpoint of solid waste, there are no other impacts of arsenic EBC implementation except for a possible increase in the impurity content of the smelter slags. This could occur as a result of recycling additional flue dust enriched in arsenic and other volatile impurities to the smelting furnace, thus increasing the effective feed of these materials to the slag-producing furnace and converter operations.

### 3.4.2 Energy Impacts

Additional energy would be required to operate the new pollution control equipment needed to attain EBC for arsenic. This would consist of the energy used to operate the spray chambers for the process emission control systems (water pumping and flue gas fan requirements) and the energy required to operate the fabric filter systems and air curtain/secondary hood systems for fugitive emission controls. The annual estimated incremental energy requirement for a typical smelter requiring both process and fugitive emission control systems is approximately $2 \times 10^4$ Gj ($5 \times 10^6$ kWh).

### 3.4.3 Control Cost Impacts

The capital and annualized costs associated with the implementation of the arsenic EBC option in the primary copper smelting industry are summarized in Table 3-9. The total incremental annual cost in final quarter 1981 dollars associated with implementing arsenic EBC in the entire industry is estimated to be $36.7 million. This estimate is based only on the cost of the pollution control equipment required beyond that associated with the regulatory baseline. The methods used to obtain the cost estimates are summarized in Appendix B-3.

## TABLE 3-9. CAPITAL AND ANNUALIZED COSTS OF EBC FOR PRIMARY COPPER SMELTERS

| PLANT | PLANT CAPACITY (Mg/yr) | TOTAL BASELINE ARSENIC EMISSIONS (kg/hr) | CONTROL EQUIPMENT REQUIRED TO REACH ARSENIC EBC | ACHIEVABLE ARSENIC EMISSIONS REDUCTION RELATIVE TO BASELINE CONTROL (kg/hr) | INSTALLED TOTAL CAPITAL COST OF REQUIRED EQUIPMENT ($10^3$ $) | TOTAL ANNUALIZED COST OF REQUIRED EQUIPMENT ($10^3$ $/yr) | COST OF CONTROL PER Mg ARSENIC REMOVED ($/Mg) |
|---|---|---|---|---|---|---|---|
| ASARCO/ El Paso | 106,000 | 2.9 | None | - | - | - | - |
| ASARCO/ Hayden | 163,000 | 3.1 | 2<br>3 | 1.9<br>0.14 | 11,300<br>1,370 | 3,090<br>510 | $1.8 \times 10^5$<br>$4.2 \times 10^5$ |
| Kennecott/ Hayden | 73,000 | 4.4 | 1<br>2<br>3 | 3.1<br><br>0.11 | 316<br>7,868<br>707 | 116<br>2,160<br>363 | $4.2 \times 10^3$<br>$3.3 \times 10^5$<br>$3.7 \times 10^5$ |
| Kennecott/ Hurley | 73,000 | 0.0045 | 2<br>3 | 0.0018<br>0.0006 | 9,609<br>707 | 2,419<br>363 | $1.7 \times 10^8$<br>$9.1 \times 10^7$ |
| Kennecott/[a] McGill | 65,000 | 2.0 | 2<br>3 | 0.20<br>0.0095 | 6,076<br>466 | 1,450<br>285 | $9.4 \times 10^5$<br>$3.4 \times 10^6$ |
| Kennecott/ Garfield | 254,000 | 2.0 | 2<br>3 | 1.0<br>0.16 | 9,609<br>1,873 | 2,419<br>666 | $3.0 \times 10^5$<br>$4.9 \times 10^5$ |
| Phelps Dodge/ Morenci | 161,000 | 0.89 | 2<br>3 | 0.61<br>0.09 | 16,037<br>1,300 | 4,019<br>507 | $7.5 \times 10^5$<br>$6.4 \times 10^5$ |
| Phelps Dodge/[a] Douglas | 115,000 | 0.96 | 2 | 0.43 | 11,306 | 3,090 | $8.2 \times 10^5$ |

[a] The Kennecott/McGill and Phelps Dodge/Douglas smelters are expected to close. The costs and emission reductions shown are relevant only if these smelters decide to upgrade their existing process emission control systems to achieve compliance with the regulatory baseline.

CONTROL EQUIPMENT KEY:

1 = Spray chamber/cooling capacity for furnace process arsenic emissions
2 = Air curtain/3rd hood with FF for converter fugitive arsenic emissions
3 = FF system for furnace fugitive arsenic emissions

## TABLE 3-9. *Continued*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Phelps Dodge/<br>Ajo | 64,000 | 5.2 | 2<br>3 | 1.28<br>0.25 | 7,868<br>691 | 2,160<br>999 | $1.9 \times 10^5$<br>$1.5 \times 10^5$ |
| Phelps Dodge/<br>Hidalgo | 127,000 | 0.53 | 2<br>3 | 0.18<br>0.03 | 6,976<br>1,090 | 1,650<br>666 | $1.03 \times 10^6$<br>$1.73 \times 10^6$ |
| Copper Range/<br>White Pine | 82,000 | 0.45 | 1<br>2<br>3 | 0.36<br>0.036<br>0.005 | 1,160<br>6,976<br>766 | 566<br>1,650<br>358 | $1.60 \times 10^5$<br>$5.2 \times 10^6$<br>$8.9 \times 10^6$ |
| Magma/[b]<br>San Manuel | 181,000 | 3.1 | 1<br>2<br>3 | 2.4<br>0.12<br>0.02 | 566<br>6,976<br>1,499 | 156<br>1,650<br>947 | $7.40 \times 10^3$<br>$1.6 \times 10^6$<br>$3.4 \times 10^6$ |
| Inspiration/<br>Miami | 136,000 | 1.0 | 2<br>3 | 0.45<br>0.09 | 11,366<br>1,153 | 3,090<br>666 | $7.9 \times 10^5$<br>$6.1 \times 10^5$ |
| Cities Service/<br>Copperhill | 20,000 | 0.011 | 2<br>3 | $7.6 \times 10^{-6}$<br>$1.6 \times 10^{-6}$ | 6,976<br>253 | 1,650<br>275 | $2.5 \times 10^8$<br>$1.9 \times 10^8$ |

[b] The cost analysis performed on the Magma/San Manuel plant conservatively assumes that the partial scrubbing system that may be installed to achieve compliance with the regulatory baseline will have a negligible effect on arsenic emissions from the smelting furnace.

CONTROL EQUIPMENT KEY:

1 = Spray chamber/cooling capacity for furnace process arsenic emissions
2 = Air curtain/2° hood with FF for converter fugitive arsenic emissions
3 = FF system for furnace fugitive arsenic emissions

The costs shown in Table 3-9 served as the inputs to an industry-wide economic impact analysis. This analysis is discussed in the next section.

### 3.4.4 Economic Impact Resulting from EBC

An economic impact analysis was conducted for the primary copper smelting plants to estimate the potential impact of requiring EBC. Using the cost data in Table 3-9 and the methodology given in Appendix C, revenue and product price increases, required by smelters to maintain the same net present values before and after the installation of EBC, were estimated. To test the sensitivity of the economic impact results to the various input data, a sensitivity analysis was conducted for each smelter, assuming simultaneous 15 percent decreases in baseline price and annual output and a 15 percent increase in the weighted cost of capital.

The annual revenue increases required by the primary copper smelting plants to maintain their profitability range from $1.7 million up to $4.1 million. The plant with the lowest required revenue increase indicates the highest unit price increase of nearly 11¢ per kg (5¢ per lb) and the greatest percent unit price increase of 4.6 percent. The lowest unit price increase was 1.5¢ per kg (0.68¢ per lb) or 0.6 percent. The revenue and price impacts of EBC in primary copper smelters is summarized in Table 3-10.

The sensitivity analysis showed that plants would incur a slight rise in the price increases needed to maintain profitability. The plant with the EBC-required increase of 4.6 percent also indicated the highest increase in the sensitivity analysis, 6.7 percent. Sensitivity analysis results for primary copper smelters are summarized in Table 3-11.

## 3.5 POPULATION EXPOSURE DATA

The data in Table 3-12 were developed during this study for use in an air pollution dispersion model to estimate the population exposure to arsenic from primary copper smelters. The Strategies and Air Standards Division (SASD) of EPA is using these data in an ongoing effort to estimate exposure to arsenic from this source category.

## 3.6 EASE OF STANDARDS DEVELOPMENT

The major impediment to arsenic standards development in the primary copper smelting industry is that the EBC options for the largest generally uncontrolled arsenic emission source in the industry (converter fugitives) have not been adequately demonstrated in the United States. In particular the air curtain/secondary hood system recommended as converter fugitive EBC has been used successfully in Japan but not in the United States. An experimental air curtain/hood system recently installed at the ASARCO/Tacoma facility has not yet been tested for arsenic removal efficiency. Until such test data are available the feasibility of applying the domestically available converter fugitive emission control designs is uncertain.

## TABLE 3-10. REVENUE AND PRICE IMPACTS FOR PRIMARY COPPER SMELTERS TO ACHIEVE EBC

| Model plant | Required revenue increase (000 dollars) | Required unit price increase (dollars per kg) | Required percent unit price increase |
|---|---|---|---|
| ASARCO/Hayden | 3,288.3 | .025 | 1.1 |
| Kennecott/Hayden | 2,377.3 | .041 | 1.7 |
| Kennecott/Hurley | 2,707.7 | .046 | 2.0 |
| Kennecott/McGill | 1,773.5 | .049 | 2.1 |
| Kennecott/Garfield | 3,002.0 | .015 | 0.6 |
| Phelps Dodge/Morenci | 4,132.2 | .032 | 1.4 |
| Phelps Dodge/Douglas | 2,811.3 | .031 | 1.3 |
| Phelps Dodge/Ajo | 2,252.4 | .044 | 1.9 |
| Phelps Dodge/Hidalgo | 1,913.5 | .019 | 0.8 |
| Copper Range/While Pine | 2,314.9 | .035 | 1.5 |
| Magma/San Manuel | 2,144.2 | .015 | 0.6 |
| Inspiration/Miami | 3,246.8 | .030 | 1.3 |
| Cities Service/Copperhill | 1,719.3 | .108 | 4.6 |

## TABLE 3-11. SENSITIVITY ANALYSIS OF THE REVENUE AND PRICE IMPACTS FOR PRIMARY COPPER SMELTERS

| Model plant | Required revenue increase (000 dollars) | Required unit price increase (dollars per kg) | Required percent unit price increase |
|---|---|---|---|
| ASARCO/Hayden | 3,473.9 | .031 | 1.6 |
| Kenneth/Hayden | 2,508.0 | .051 | 2.5 |
| Kennecott/Hurley | 2,859.3 | .058 | 2.9 |
| Kennecott/McGill | 1,870.0 | .061 | 3.1 |
| Kennecott/Garfield | 3,170.7 | .018 | 0.9 |
| Phelps Dodge/Morenci | 4,366.6 | .040 | 2.0 |
| Phelps Dodge/Douglas | 2,977.5 | .038 | 1.9 |
| Phelps Dodge/Ajo | 2,377.3 | .055 | 2.8 |
| Phelps Dodge/Hidalgo | 2,018.3 | .023 | 1.2 |
| Copper Range/While Pine | 2,432.2 | .044 | 2.2 |
| Magma/San Manuel | 2,262.0 | .018 | 0.9 |
| Inspiration/Miami | 3,430.0 | .037 | 1.9 |
| Cities Service/Copperhill | 1,812.3 | .133 | 6.7 |

## TABLE 3-12. POPULATION EXPOSURE MODELLING INPUT DATA FOR THE PRIMARY COPPER SMELTING INDUSTRY

| PLANT LOCATION | UTM COORDINATES (km) | EMISSION POINT | STACK PARAMETERS |  |  |  |  | ARSENIC EMISSIONS |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Height m (ft) | Diameter m (ft) | Exit Temp. °K (°F) | Flow Rate $m^3$/sec (acfm) | Flow Velocity m/sec (ft/sec) | Baseline kg/hr (lb/hr) | EBC kg/hr (lb/hr) |
| ASARCO | Zone | Cu Roaster/Pb-Sinter/AP Stack | 40 (131)$^{11}$ | 2.7 (8.9)$^{11}$ | 337 (147)$^{11}$ | 42.5 (90,000)$^{15}$ | 7.4 (24.3)$^{15}$ | Negligible by Comparison |  |
| El Paso, TX | Hor 346.3<br>Vert 3517.5 | Cu Reverb Stack | 252 (828)$^{12}$ | 4.9 (16.1)$^{12}$ | 366 (200)$^{12}$ | 106 (225,000)$^{15}$ | 5.6 (18.4)$^{15}$ | 2.3 (5.1)$^{9}$ | 2.3 (5.1)$^{9}$ |
|  |  | Cu Conv. | 31 (100)$^{12}$ | 1.7 (5.6)$^{12}$ | 339 (150)$^{12}$ | 33.6 (71,000)$^{10}$ | 14.8 (48.6) | 0.08 (0.18)$^{15}$ | 0.08 (0.18)$^{15}$ |
|  |  | Sb Recovery Process Stack | 46 (150)$^{15}$ | 1.2 (3.9)$^{15}$ | 308 (95)$^{15}$ | 20.3 (43,000)$^{15}$ | 17.9 (58.9)$^{15}$ | 0.23 (0.5)$^{15}$ | 0.23 (0.5)$^{15}$ |
|  |  | Reverb. Fug. |  |  | 339 (150)$^{13}$ | 24.8 (52,000)$^{13}$ |  | 0.05 (0.12)$^{9}$ | 0.05 (0.12)$^{9}$ |
|  |  | Conv. Bldg. Evacuation Sys. | 252 (828)$^{15}$ |  | 339 (150)$^{13}$ | 280 (600,000)$^{12}$ |  | 0.11 (0.25)$^{15}$ | 0.11 (0.25)$^{15}$ |
| ASARCO<br>Hayden, AZ | Zone 12<br>Hor 529.8<br>Vert 3652.0 | Main Stack | 305 (1000)$^{12}$ | 5.2 (17.0)$^{12}$ | 394 (250)$^{15}$ | 269 (570,000)$^{11}$ | 12.7 (41.5) | 0.8 (1.7)$^{13}$ | 0.8 (1.7)$^{13}$ |
|  |  | Reverb Fug. |  |  | 339 (150)$^{11}$ | 38.8 (82,000)$^{13}$ |  | 0.16 (0.35)$^{9}$ | 0.05 (0.11)$^{13}$ |
|  |  | Conv. Secondary | 305 (1000)$^{15}$ |  | 339 (150)$^{11}$ | 142 (300,000)$^{15}$ |  | 5.7 (12.5)$^{15}$ | 0.77 (1.7)$^{15}$ |
| Kennecott | Zone 12 | Roaster/Conv./AP Stack | 30.5 (100)$^{12}$ | 2.4 (7.9)$^{12}$ | 352 (174)$^{11}$ | 47.2 (100,000)$^{11}$ | 10.4 (34.2) | Negligible by Comparison |  |
| Hayden, AZ | Hor 520.5<br>Vert 3652.4 | Reverb Stack | 183 (600)$^{12}$ | 5.2 (17.0)$^{12}$ | 533 (500)$^{11}$ | 61.4 (130,000)$^{11}$ | 2.9 (9.5) | 3.5 (7.7)$^{9}$ | 0.38 (0.84)$^{13}$ |
|  |  | Reverb Fug. |  |  | 339 (150)$^{13}$ | 17.4 (37,000)$^{13}$ |  | 0.12 (0.26)$^{9}$ | 0.02 (0.04)$^{13}$ |
|  |  | Conv. Fug. |  |  | 339 (150)$^{13}$ | 94.5 (200,000)$^{13}$ |  | 0.81 (1.8)$^{9}$ | 0.07 (0.15)$^{13}$ |
| Kennecott<br>Hurley, NM | Zone 12<br>Hor 169.2<br>Vert 3621.2 | Main Stack | 155 (508)$^{12}$ | 7.9 (25.9)$^{12}$ | 422 (300)$^{11}$ | 109 (230,000)$^{11}$ | 2.2 (7.3) | 0.002 (0.005)$^{13}$ | 0.002 (0.005)$^{13}$ |
|  |  | Conv/AP Stack | 61 (200)$^{12}$ | 3.1 (10.2)$^{12}$ | 339 (150)$^{12}$ | ND | ND | Negligible by Comparison |  |
|  |  | Reverb Fug. |  |  | 339 (150)$^{13}$ | 17.4 (37,000)$^{13}$ |  | $5x10^{-4}$ $(1.1x10^{-3})^{9}$ | $6.8x10^{-5}$ $(1.5x10^{-4})^{13}$ |
|  |  | Conv. Fug. |  |  | 339 (150)$^{13}$ | 126 (267,000)$^{13}$ |  | $2x10^{-3}$ $(4.4x10^{-3})^{9}$ | $1.8x10^{-4}$ $(4.0x10^{-4})^{13}$ |
| Kennecott<br>McGill, NV | Zone 11<br>Hor 691.2<br>Vert 4363.7 | Main Stack | 229 (750)$^{12}$ | 4.7 (15.4)$^{12}$ | 422 (300)$^{11}$ | 354 (750,000)$^{11}$ | 20.4 (67.0) | 1.8 (3.9)$^{13}$ | 1.8 (3.9)$^{13}$ |
|  |  | Reverb Fug. |  |  | 339 (150)$^{13}$ | 10.7 (23,000)$^{13}$ |  | 0.01 (0.02)$^{9}$ | $1.5x10^{-3}$ $(3.3x10^{-3})^{13}$ |
|  |  | Conv. Fug. |  |  | 339 (150)$^{13}$ | 94.5 (200,000)$^{13}$ |  | 0.2 (0.5)$^{9}$ | 0.019 (0.043)$^{13}$ |
| Kennecott<br>Garfield, UT | Zone 12<br>Hor 399.4<br>Vert 4363.7 | Main Stack | 366 (1200)$^{11}$ | 7.3 (23.9)$^{14}$ | 339 (150)$^{11}$ | 472 (1,000,000)$^{11}$ | 11.3 (37.0) | 0.7 (1.4)$^{9}$ | 0.7 (1.4)$^{9}$ |
|  |  | Furnace Fug. |  |  | 339 (150)$^{13}$ | 60.5 (128,000)$^{13}$ |  | 0.18 (0.40)$^{9}$ | 0.03 (0.06)$^{13}$ |
|  |  | Conv. Fug. |  |  | 339 (150)$^{13}$ | 126 (267,000)$^{13}$ |  | 1.1 (2.4)$^{9}$ | 0.10 (0.21)$^{13}$ |
| Phelps Dodge | Zone 12 | Roaster/Conv./AP Stack | 184 (603)$^{12}$ | 9.1 (29.8)$^{12}$ | 352 (174)$^{11}$ | 244 (520,000)$^{11}$ | 3.8 (12.3) | 0.12 (0.26)$^{13}$ | 0.12 (0.26)$^{13}$ |
| Morenci, AZ | Hor 654.8<br>Vert 3659.8 | Reverb Stack | 184 (603)$^{12}$ | 9.1 (29.8)$^{12}$ | 533 (500)$^{11}$ | 223 (472,000)$^{11}$ | 3.4 (11.2) | 0.10 (0.22)$^{9}$ | 0.014 (0.031)$^{13}$ |
|  |  | Reverb Fug. |  |  | 339 (150)$^{13}$ | 38.3 (81,000)$^{12}$ |  | 0.67 (1.48)$^{9}$ | 0.059 (0.130)$^{13}$ |
|  |  | Conv. Fug. |  |  | 339 (150)$^{13}$ | 220 (467,000)$^{13}$ |  |  |  |

## TABLE 3-12. Continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Phelps Dodge<br>Douglas, AZ | Zone 12<br>Hor 634.5<br>Vert 3468.6 | Roaster/Reverb Stack | 166 (544)[12] | 6.7 (22.0)[12] | 480 (405)[11] | 137 (290,000)[11] | 3.9 (12.7) | 0.21 (0.46)[13] | 0.21 (0.46)[13] |
| | | Conv. Stack | 172 (564)[12] | 5.5 (18.0)[12] | 450 (350)[11] | 112 (237,000)[11] | 4.7 (15.5) | 0.21 (0.46)[13] | 0.21 (0.46)[13] |
| | | Reverb Fug. | | | 339 (150)[13] | 27.4 (58,000)[13] | | 0.07 (0.15)[9] | 0.01 (0.02)[13] |
| | | Conv. Fug. | | | 339 (150)[13] | 157.5 (333,000)[13] | | 0.47 (1.04)[9] | 0.04 (0.09)[13] |
| Phelps Dodge<br>Ajo, NM | Zone 12<br>Hor 325.6<br>Vert 3582.7 | Reverb Stack | 110 (361)[11] | 4.6 (15.1)[11] | 373 (212)[11] | 114 (240,000)[11] | 6.9 (22.5) | 2.0 (4.3)[13] | 2.0 (4.3)[13] |
| | | Conv./AP Stack | 110 (361)[11] | ND | ND | ND | ND | 1.5 (3.3)[13] | 1.5 (3.3)[13] |
| | | Reverb Fug. | | | 339 (150)[13] | 15.2 (32,000)[13] | | 0.29 (0.64)[9] | 0.04 (0.09)[13] |
| | | Conv. Fug. | | | 339 (150)[13] | 94.5 (200,000)[13] | | 1.4 (3.08)[9] | 0.123 (0.271)[13] |
| Phelps Dodge<br>Hidalgo, NM | Zone 12<br>Hor 734.0<br>Vert 3517.0 | Flash Furn./Conv./ AP Stack | 61 (200)[11] | 2.3 (7.5)[14] | 380 (225)[14] | 18.3 (39,000)[14] | 4.4 (14.4) | 0.3 (0.7)[9] | 0.3 (0.7)[9] |
| | | Slag Furn. Stack | 183 (600)[14] | 5.5 (18.0)[14] | 644 (700)[14] | 75.8 (160,000)[14] | 3.2 (10.5) | Negligible by Comparison | |
| | | Furn. Fug. | | | 339 (150)[13] | 30.2 (64,000)[13] | | 0.03 (0.07)[9] | 0.005 (0.11)[13] |
| | | Conv. Fug. | | | 339 (150)[13] | 62.8 (133,000)[13] | | 0.20 (0.44)[9] | 0.02 (0.040)[13] |
| Copper Range<br>White Pines,<br>MI | Zone 16<br>Hor 302.7<br>Vert 5180.8 | Conv./Rev. Stack | 154 (505)[11] | 4.6 (15.1)[11] | 494 (430)[11] | 100 (212,000)[11] | 6.0 (19.7) | 0.41 (0.9)[9] | 0.05 (0.10)[13] |
| | | Reverb. Fug. | | | 339 (150)[13] | 19.5 (41,000)[13] | | 0.0053 (0.012)[9] | $7.2 \times 10^{-4}$ ($1.6 \times 10^{-3}$)[13] |
| | | Conv. Fug. | | | 339 (150)[13] | 62.8 (133,000)[13] | | 0.04 (0.09)[9] | 0.004 (0.08)[13] |
| Magma<br>San Manuel,<br>AZ | Zone 12<br>Hor 535.4<br>Vert 3608.6 | Reverb. Stack | 155 (508)[12] | 6.4 (21.0)[12] | 519 (475)[11] | 189 (400,000)[11] | 5.9 (19.3) | 2.8 (6.2)[9] | 0.4 (0.9)[13] |
| | | Conv./AP Stack | 76 (249)[12] | 2.9 (9.5)[12] | 325 (125)[11] | 88.3 (187,000)[11] | 13.4 (43.8) | 0.1 (0.2)[9] | 0.2 (0.5)[13] |
| | | Reverb. Fug. | | | 339 (150)[13] | 43.1 (91,000)[13] | | 0.021 (0.046)[9] | 0.003 (0.006)[13] |
| | | Conv. Fug. | | | 339 (150)[13] | 62.8 (133,000)[13] | | 0.13 (0.29)[9] | 0.01 (0.2)[13] |
| Inspiration<br>Miami, AZ | Zone 12<br>Hor 513.4<br>Vert 3696.7 | E. Furn./Conv. AP Stack | 61.0 (200)[11] | 3.1 (10.2)[11] | 327 (129)[11] | 53.7 (114,000)[10] | 7.1 (23.3) | 0.4 (1.0)[9] | 0.4 (1.0)[9] |
| | | Furn. Fug. | | | 339 (150)[13] | 32.4 (69,000)[13] | | 0.10 (0.22)[9] | 0.01 (0.30)[13] |
| | | Conv. Fug. | | | 339 (150)[13] | 62.8 (133,000)[13] | | 0.49 (1.1)[9] | 0.04 (0.09)[13] |
| Cities Services<br>Copperhill,<br>TN | Zone 16<br>Hor 740.0<br>Vert 3874.8 | AP 4,5 | 61.0 (200)[10] | | 339 (150)[13] | 53.7 (114,000)[13] | | (0.005)[13] | (0.005)[13] |
| | | AP 6 | 76.2 (250)[10] | | 339 (150)[13] | 53.7 (114,000)[13] | | (0.005)[13] | (0.005)[13] |
| | | Furn. Fug. | | | 339 (150)[13] | 4.8 (10,000)[13] | | $2 \times 10^{-4}$ ($3 \times 10^{-4}$)[13] | $3 \times 10^{-5}$ ($6 \times 10^{-5}$)[13] |
| | | Conv. Fug. | | | 339 (150)[13] | 62.8 (133,000)[13] | | $8 \times 10^{-4}$ ($2 \times 10^{-3}$)[13] | $2 \times 10^{-4}$ ($4 \times 10^{-4}$)[13] |

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# 4.0 PRIMARY LEAD SMELTING

This chapter discusses the primary lead smelting industry and its associated arsenic emissions. Section 4.1 presents a brief source catagory description. Section 4.2 discusses the regulations currently covering the industry and the resulting level of control and associated arsenic emissions. Section 4.3 presents a discussion of the EBC options. Section 4.4 presents the input data to be used in assessing the population exposure to arsenic emissions from primary lead smelting. The ease of standards development is discussed in Section 4.5.

## 4.1 LEAD SMELTING DESCTIPTION

### 4.1.1 General Information

Metallic lead is produced from lead ore concentrates at primary lead smelters. The United States' primary lead smelters produced 578,000 Mg (636,000 tons) of lead in 1979, which accounted for 41 percent of the total domestic demand for lead in that year.[1] There are currently four companies and five individual plants that produce primary lead bullion in the United States. Table 4-1 lists the names, locations, production capacities, and estimated total inorganic arsenic emission rates of the plants. The existing total annual inorganic arsenic emission rate from the entire primary lead smelting industry is estimated to be about 43 Mg/yr (47 tons/yr).

### 4.1.2 Process Description

The materials processed at the U. S. primary lead smelters are predominantly sulfide ore concentrates. The most important lead-containing mineral in the ore concentrates is Galena (PbS). Commercially significant raw lead ore as mined is typically 3 to 6 percent lead by weight, and gravity/flotation methods are used to concentrate the ore. Two major types of lead ore concentrates are smelted in the United States: Missouri lead ore concentrates, which account for 83 percent of the domestic primary lead production, and western lead ore concentrates, which account for 10 percent of the domestic primary lead production. Concentrates originating from foreign lead ore account for the remainder. Lead ore concentrates from the Missouri lead belt typically contain about 75 percent lead and 15 percent sulfur by weight, with silver, copper, zinc, iron, calcium, magnesium, arsenic, and acid-insoluble material making up most of the remaining 10 weight percent. Western lead ore concentrates are of poorer quality than Missouri lead ore concentrates and contain about 45 percent lead, 10 to 30 percent sulfur, up to 15 percent zinc, 8 percent iron, and 3 percent

TABLE 4-1. THE DOMESTIC PRIMARY LEAD SMELTERS

| Plant | Location | Production Capacity[a] (Mg/yr) | Production Capacity[a] (tons/yr) | Estimated Total Inorganic Arsenic Emission Rate[b] (Mg/yr) | Estimated Total Inorganic Arsenic Emission Rate[b] (tons/yr) |
|---|---|---|---|---|---|
| ASARCO/El Paso | El Paso, Texas | 82,000 | 90,000 | 12.3 | 13.5 |
| ASARCO/East Helena | East Helena, Montana | 82,000 | 90,000 | 24.1 | 26.5 |
| ASARCO/Glover | Glover, Missouri | 100,000 | 110,000 | 1.8 | 2.0 |
| AMAX/Boss | Boss, Missouri | 127,000 | 140,000 | 1.8 | 2.0 |
| St. JOE/Herculaneaum | Herculaneum, Missouri | 204,000 | 225,000 | 3.0 | 3.3 |

[a] 1979 capacity figures listed in terms of lead produced per year.

[b] Estimated annual arsenic emission rates based on the methods shown in Appendix A.

copper. Other constituents of western lead ore concentrates include gold, silver, calcium, magnesium, antimony, bismuth, and arsenic.

Arsenic generally appears in the form of arsenopyrite (FeAsS) or arsenic sulfide ($As_2S_3$) in lead-bearing ores. The gravity/flotation methods used to concentrate the lead bearing fraction of the raw ores also concentrate arsenic. The arsenic content of Missouri lead ore concentrate is typically about 0.02 percent by weight, while western lead ore concentrates contain about 0.1 to 0.4 percent arsenic by weight.[2]

Fugitive emissions associated with lead ore handling and storage are controlled by ventilated enclosure systems and wet suppression methods. Ore transfer points are generally hooded and vented to fabric filter or venturi scrubber systems.

As shown in Figure 4-1, primary lead smelting is a complex process with several distinct operations. The three key operations common to all U. S. primary lead smelters are sintering, blast furnace reduction, and drossing. Other significant process steps are those associated with the dross reverberatory furnace, the slag fuming furnace, the deleading kiln, and the lead refinery. Impure lead bullion produced by the smelting process can either be refined on-site (as is the case for the Missouri lead smelters) or shipped elsewhere for refining (as is the case for ASARCO/East Helena and ASARCO/El Paso).

The first step in the processing of lead ore concentrates is sintering, which is carried out in an oxidizing atmosphere at a temperature of about 600°C (1100°F). Lead sintering is essentially a roasting operation that also serves to agglomerate the feed materials into a form suitable for blast furnace reduction. Several functions are performed by lead sintering:

(i) a large portion of the sulfur in the ore concentrate is removed as $SO_2$ or $SO_3$, thereby allowing for the operation of a low temperature, high efficiency blast furnace operation.
(ii) readily melting complex silicates are formed that agglomerate the charge into a hard, porous blast furnace feed.
(iii) species such as cadmium, arsenic trioxide, and antimony trioxide are removed by volatilization.

Updraft-type sintering machines are used exclusively in the domestic lead smelting industry. The ore concentrate charge is spread onto the grate bottoms of iron pallets that move through the sinter machine on a circular belt. Air is introduced through wind-boxes located below the sinter charge and passes through the charge to participate in the sintering oxidation reactions. The sintering reactions are sufficiently exothermic to sustain the desired temperature of 600°C (1100°F) once the charge is ignited. Approximately 80 percent of the sulfur in the ore concentrate is eliminated as $SO_2$ from the sintering machine. The product sinter is screened to remove fines and sent to the blast furnace.

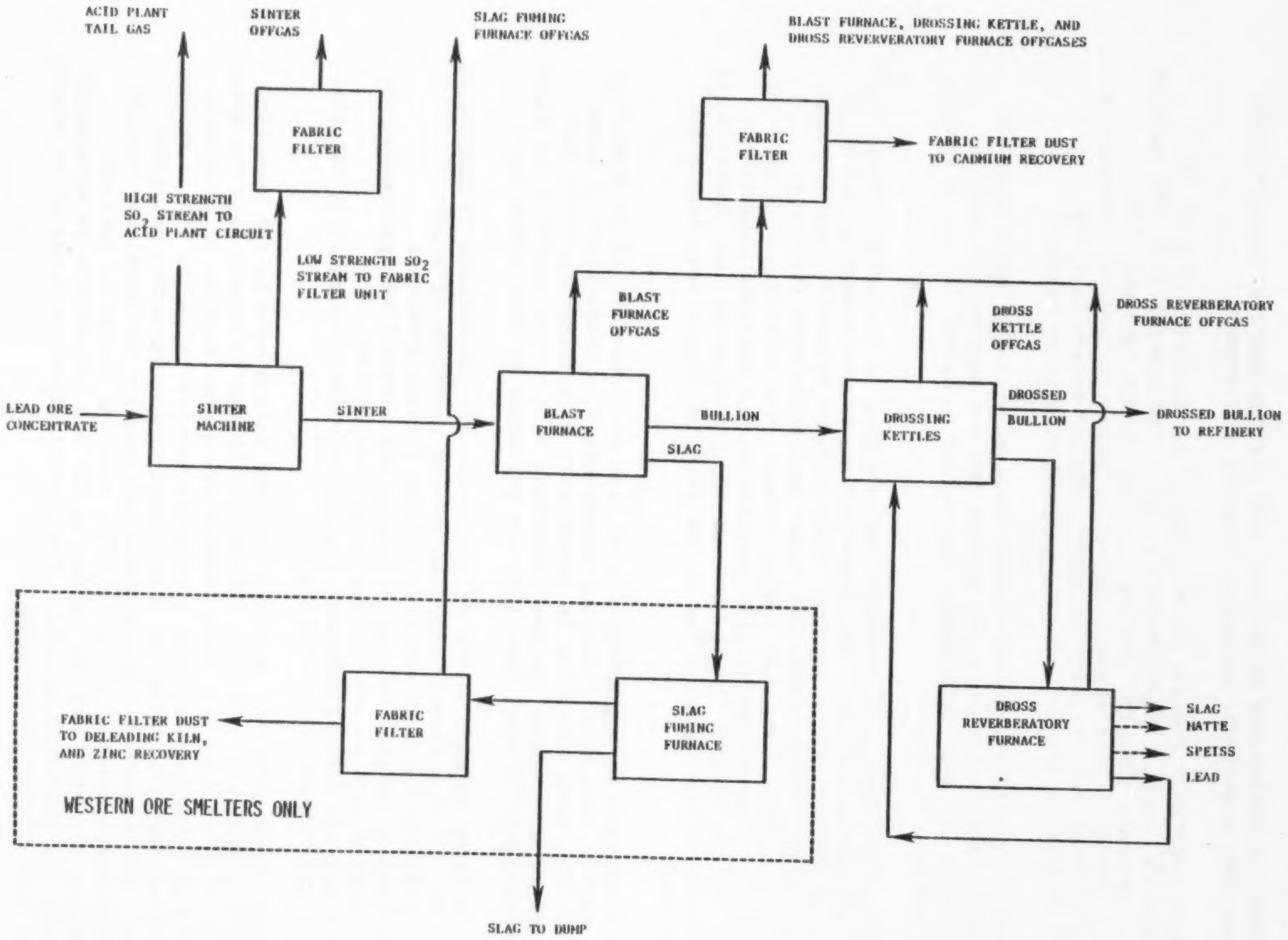
ACID PLANT TAIL GAS
SINTER OFFGAS
SLAG FUMING FURNACE OFFGAS
BLAST FURNACE, DROSSING KETTLE, AND DROSS REVERVERATORY FURNACE OFFGASES
FABRIC FILTER
FABRIC FILTER
FABRIC FILTER DUST TO CADMIUM RECOVERY
HIGH STRENGTH SO$_2$ STREAM TO ACID PLANT CIRCUIT
LOW STRENGTH SO$_2$ STREAM TO FABRIC FILTER UNIT
BLAST FURNACE OFFGAS
DROSS KETTLE OFFGAS
DROSS REVERBERATORY FURNACE OFFGAS
LEAD ORE CONCENTRATE
SINTER MACHINE
SINTER
BLAST FURNACE
BULLION
SLAG
DROSSING KETTLES
DROSSED BULLION
DROSSED BULLION TO REFINERY
FABRIC FILTER DUST TO DELEADING KILN, AND ZINC RECOVERY
FABRIC FILTER
SLAG FUMING FURNACE
WESTERN ORE SMELTERS ONLY
DROSS REVERBERATORY FURNACE
SLAG
MATTE
SPEISS
LEAD
SLAG TO DUMP

Figure 4-1. Primary lead smelting.

Four of the five operating primary lead smelters use contact sulfuric acid plants and the associated gas pre-cleaning equipment to treat some or all of the sinter machine offgases. The ASARCO/Glover lead smelter has no sinter machine $SO_2$ control, sinter machine offgases at ASARCO/Glover are sent to a spray chamber/fabric filter system operated at 125°C (257°F) for particulate control only.[3] Three of the four smelters with acid plant units (ASARCO/East Helena, AMAX/Boss, and St. Joe/Herculaneum) treat two separate offgas streams from the sinter machine. A concentrated $SO_2$ offgas stream is removed from the inlet end of the sinter machine and treated in an acid plant circuit, and a dilute $SO_2$ offgas stream is removed from the outlet end of the sinter machine and treated in a fabric filter system operated at 100 to 125°C (212 to 257°F).[4,5] It is not economically feasible to treat the entire offgas stream from a lead sintering machine with a contact sulfuric acid plant unless a technique is used to increase the $SO_2$ content of the stream to an acceptable level of 3.5 percent $SO_2$ or greater. The ASARCO/El Paso lead smelter makes use of a sinter machine offgas recirculation technology that allows for the production of a single sinter offgas stream containing 4 to 5 percent $SO_2$. The entire sinter machine offgas stream at ASARCO/El Paso is treated in a contact sulfuric acid plant circuit.[6]

Hooding and enclosure of emission points followed by particulate removal using fabric filter or wet scrubbing systems are the commonly used fugitive control techniques associated with sinter preparation and recovery. Sinter machine fugitive discharges are generally controlled by total or partial enclosure of the operation.

Screened sinter product is mixed with coke, recycled slag, silica, lime, and recycled flue dust and is fed to the blast furnace. At the operating temperature of the blast furnace (980 to 1035°C) the charge exists in a molten state, and several oxidation/reduction type metallurgical reactions occur. Lead oxide is reduced to metallic lead by the action of coke. Iron oxide is reduced to metallic iron which in turn reduces lead sulfide and lead oxide to metallic lead. The net result of the blast furnace reactions is the production of a metallic lead-rich phase called the lead bullion and a slag phase containing complex silicates of iron, calcium, zinc, magnesium, and aluminum oxides. Depending on the non-lead impurity levels of the ore concentrate and on the operation of the furnace, a copper-rich phase called matte and a copper/iron/antimony/arsenic-rich phase called speiss can also be formed. In most cases lead bullion and slag represent the major products from the blast furnace. They separate on the basis of their mutual insolubility, and the slag layer floats above the lead bullion. The various phases are removed individually from the furnace.

The $SO_2$ content of blast furnace offgas is typically on the order of 0.05 volume percent and too low to facilitiate treatment in a contact sulfuric acid plant. Particulate removal at all five domestic primary lead smelters is accomplished by treatment in fabric filter units operated over the temperature range of 100 to 125°C. Fugitive emissions from the blast furnaces are controlled by building enclosure of the source and by the use of fixed or movable hoods for furnace tapping operations.

Blast furnace slag contains variable amounts of lead and zinc, and its fate is determined by its composition. If the slag contains appreciable amounts of zinc, which is typical of western lead ore, it is sent to a slag fuming furnace where zinc oxide and lead oxide are separated from the gangue material and recovered. Low-zinc slag produced at the Missouri lead smelters is partially discarded and partially recycled to the sinter machine for recovery of the lead value. The slag fuming furnace offgas streams containing particulate at ASARCO/El Paso and ASARCO/East Helena are controlled with fabric filters. The operational temperature of the fabric filter systems is not known explicitly, but is assumed to be low (100 to 125°C, or 212 to 257°F) by analogy to the operation of baghouse systems on the other lead smelter process offgas streams.

Lead bullion from the blast furnace is sent to a drossing kettle where the molten bullion is cooled, thereby reducing the solubilities of the various contaminants entrained and dissolved in the lead. A dross phase forms on the surface of the lead that may contain portions of slag, matte, speiss, and lead oxide. The dross is skimmed from the surface and sent to a reverberatory dross furnace or an electric dross furnace, where it is treated with additional reagents to produce as many as four phases: slag, matte, speiss, and lead. Dross furnace slag is recycled to the blast furnace, matte and speiss (when formed) are shipped to a copper smelter, and lead is recycled to the dross kettle.

Dross kettle and dross furnace process offgases contain very small amounts of $SO_2$. They are combined with blast furnace offgases at all five domestic primary lead smelters and treated for particulate and fume removal in fabric filter units operated over the temperature range of 100 to 125°C (212 to 257°F). Fugitive emissions from the drossing kettles are generally controlled by building enclosure or kettle hooding systems.

Lead bullion from the drossing operation contains a variety of impurities that must be removed by lead refining. The three Missouri lead smelters refine lead on-site, while the ASARCO/East Helena and ASARCO/El Paso smelters ship their drossed buillion to an ASARCO lead refinery in Omaha, Nebraska. Lead refining can be a very complex operation and is highly dependent on the level and types of impurities present. Domestic lead refineries employ pyrometallurgical processes (furnace-kettle refining) that are generally based on two impurity removal strategies:

(i) Drossed bullion impurities such as antimony, arsenic, and tin are more readily oxidized than is lead. They can be removed by oxidation/volatilization or oxidation/slagging techniques.

(ii) Drossed bullion impurities such as gold, silver, copper, and bismuth can be removed in the form of insoluble intermetallic compounds with the added reagents zinc, calcium, and magnesium.

The final product of a lead refinery contains greater than 99 percent pure lead. Offgases from lead refining and other miscellaneous potential sources of arsenic emissions at primary lead smelters are controlled with fabric filter units.

### 4.1.3 The Behavior of Arsenic in Primary Lead Smelting

The arsenic content of refined lead represents less than 1 percent of the arsenic fed to the smelter in the ore concentrate. The routes of arsenic removal from the lead-bearing portion of the charge material include volatilization and slagging as well as association with the matte and speiss phases that are subsequently shipped to copper smelters. Arsenic is volatilized as arsenic trioxide from sinter plants, blast furnaces, dross reverberatory furnaces, zinc fuming furnaces, and reverberatory softening furnaces (lead refining). Slagging of arsenic occurs in the form of metallic arsenates such as iron arsenate [$Fe_3(AsO_4)_2$] from blast furnaces, dross furnaces, and slag fuming furnaces. Large quantities of arsenic are removed in the matte and speiss phases that are tapped from dross furnaces.

Table 4-2 shows the approximate distribution of arsenic among the various removal routes at a Missouri lead ore smelter.[7] A total of 87.1 percent of the arsenic entering with the plant feed is accounted for in the solid products leaving the facility. The dross stock pile is the largest single source of arsenic elimination, followed by the matte stock pile and the blast furnace slag. A total of 12.9 percent of the arsenic entering the smelter cannot be accounted for in the solid waste and product streams. This figure represents an upper bound on the fraction of the input arsenic that is emitted to the atmosphere.

Comparable information on the distribution of arsenic elimination at western ore smelters (ASARCO/East Helena and ASARCO/El Paso) is not presently available. However, it is known that large amounts of arsenic are removed from the lead-bearing material in the speiss phase tapped from the dross furnaces at these facilities. A U. S. Bureau of Mines publication reported that the average arsenic content of the speiss produced at three unspecified lead smelters was 15.8 percent by weight. The data presented in the same publication suggest that as much as 74 percent of the arsenic entering a speiss-producing lead smelter is removed in the speiss phase. Speiss produced at ASARCO/East Helena and ASARCO/El Paso lead smelters are combined with copper ore concentrates at the ASARCO/Tacoma and ASARCO/El Paso copper smelters, respectively. The fate of arsenic at primary copper smelters is discussed in Chapter 3.

## 4.2 INORGANIC ARSENIC EMISSIONS UNDER EXISTING REGULATIONS

### 4.2.1 Regulatory Impacts

The existing regulations having a direct effect on arsenic emissions from the lead smelting industry are the NSPS for $SO_2$ and particulate, the

## TABLE 4-2. ARSENIC ELIMINATION ROUTES AT THE AMAX PRIMARY LEAD SMELTER IN BOSS, MISSOURI[7]

| ARSENIC ELIMINATION ROUTE | % ARSENIC ELIMINATION[a] |
|---|---|
| Dross Stock Pile[b] | 42.4% |
| Matte Stock Pile | 28.5% |
| Blast Furnace Slag | 16.0% |
| Unaccounted Arsenic[c] | 12.9% |
| Refined Lead | 0.3% |
| Speiss Stock Pile[d] | 0.0% |

[a] The percent arsenic elimination is expressed as a percentage of the total amount of arsenic entering the plant with the ore concentrate feed.

[b] Approximately 20 percent of the dross material produced at the AMAX smelter is stored in the dross stockpile. The majority of the remainder is sent to an electric dross furnace for recovery of copper matte and lead bullion.

[c] The unaccounted arsenic was obtained by difference from material balance figures.

[d] Speiss does not form in the electric dross furnace at the AMAX smelter due to the low arsenic and antimony content of the Missouri lead ore concentrate.

SIP emission limitations for $SO_2$ and particulate, the impending SIP emission limitations for lead, and the OSHA workplace exposure standards for lead and inorganic arsenic. These regulations are discussed in greater detail in Chapter 2.

All five primary lead smelters are in compliance with their respective SIP's for $SO_2$ and particulate emissions.[9] The lead NAAQS is currently exceeded in regions surrounding four of the five primary lead smelters. The ASARCO/Glover smelter has maintained compliance with the lead NAAQS through the use of dispersion techniques facilitated by a tall [186 m (610 ft)] stack.[18] State implementation plans for achieving the lead NAAQS have not yet been developed, and at the present time it is unclear what the effect of the lead NAAQS on the primary lead smelting industry will be.

The OSHA lead standard of 50 $\mu g/m^3$ is being exceeded at all five primary lead smelters, and the OSHA arsenic standard of 10 $\mu g/m^3$ is being exceeded at two plants (ASARCO/El Paso and ASARCO/East Helena).[10] The OSHA workplace standard exceedances are primarily due to emissions from fugitive sources. The ASARCO/El Paso and ASARCO/East Helena smelters have already signed agreements with OSHA that will result in improvements in their fugitive emission control systems. The modifications are specifically designed to achieve compliance with the OSHA inorganic arsenic standard.

### 4.2.2 Arsenic Removal Capabilities of Existing Control Equipment

4.2.2.1 Process Emission Controls. Arsenic removal efficiency tests have not been conducted on any of the process emission control systems at existing primary lead smelters. However, the test work that has been done in the copper smelting industry is also applicable to the lead smelting industry. Both types of smelters are hot sources of arsenic emissions in the form of arsenic trioxide. The acid plant/gas pre-cleaning systems in use on sinter machine offgases are effective means of arsenic control due to the extensive pollutant removal capability of the pre-cleaning system. The relatively low operational temperatures (100 to 125°C, or 212 to 257°C) of the lead smelter fabric filter systems in conjunction with the copper smelter fabric filter test data, support the conclusion that high arsenic removal efficiencies are being achieved on lead smelter offgas streams that are low in $SO_2$ content. Without the benefit of actual arsenic removal test data, it is estimated by analogy to the copper smelter data that arsenic removal efficiencies greater than 90 percent are currently being achieved by existing acid plant and fabric filter systems.

4.2.2.2 Fugitive Emission Controls. Test data are not available to determine the arsenic removal efficiencies of existing lead smelter fugitive emission control systems. By analogy to the copper smelting industry, it is expected that the best available ventilation capture systems should be capable of approximately 90 percent fugitive arsenic emission capture. The performance of existing ventilation systems in the primary lead smelting industry is expected to be below this level.

### 4.2.3 Inorganic Arsenic Emissions Under the Regulatory Baseline

Arsenic emissions testing has been performed at two primary lead smelters. Process and fugitive emissions test results are available for the ASARCO/East Helena facility, and fugitive emissions test results are available for ASARCO/Glover.[11,12] The testing was designed only to determine arsenic emissions from the two plants. Arsenic removal efficiencies of the existing control devices were not measured.

4.2.3.1 Process Emissions Testing. Table 4-3 summarizes the results of the process arsenic emissions testing done at ASARCO/East Helena. The sum of the measured process arsenic emissions rates from the plant was 2.2 kg/hr (4.8 lb/hr). Tests more recently conducted at East Helena by the Montana State Department of Health and Environmental Sciences/Air Quality Bureau indicate that the total arsenic emission rate (process and fugitive emissions combined) is only 0.63 kg/hr (1.4 lb/hr).[13] A test report describing this more recent work will be available by mid-1982.

4.2.3.2 Fugitive Emissions Testing. The results of the fugitive arsenic emissions testing performed at ASARCO/East Helena and ASARCO/Glover are summarized in Tables 4-4 and 4-5. The arsenic contents of the ore concentrates processed at ASARCO/East Helena and ASARCO/Glover are about 0.4 and 0.02 weight percent, respectively. The relative magnitudes of the arsenic emission estimates demonstrate that fugitive arsenic emissions from a plant smelting high-arsenic lead ore concentrate (0.1 to 0.4 percent arsenic by weight) are much greater than those from a plant smelting low-arsenic lead ore concentrate (0.02 percent arsenic by weight). The largest source of fugitive arsenic emissions at the ASARCO/Glover smelter was found to be the blast furnace operation, which accounted for 84 percent of the total fugitive arsenic emissions. The dross reverberatory building was found to be the largest source of fugitive arsenic emissions at ASARCO/East Helena, accounting for 96 percent of the measured fugitive arsenic emissions. The disparity in the relative magnitudes of the arsenic emissions from the various sources at the two plants is due largely to the fact that ASARCO/Glover does not have a dross reverberatory furnace operation. Fugitive arsenic emissions at ASARCO/East Helena represent about 22 percent of the total estimated arsenic emissions from the plant (2.75 kg/hr). The arsenic emissions study more recently undertaken by the State of Montana indicates that fugitive arsenic emissions represent a much larger fraction of the total arsenic emissions.[13]

## 4.3 ARSENIC EBC OPTIONS FOR THE PRIMARY LEAD SMELTING INDUSTRY

### 4.3.1 Definition of Arsenic EBC

Arsenic EBC for process emissions from primary lead smelters is defined by analogy to arsenic EBC in the primary copper smelting industry. Contact sulfuric acid plants and the associated gas pre-cleaning systems are recommended for the treatment of concentrated $SO_2$ offgas streams produced in

TABLE 4-3. MEASURED PROCESS ARSENIC EMISSION RATES AT THE ASARCO/EAST HELENA LEAD SMELTER[11]

| Stack Identification | Process Offgas Served | Inorganic Arsenic Emissions kg/hr | Inorganic Arsenic Emissions (lb/hr) | % of Total Process Arsenic Emissions |
|---|---|---|---|---|
| Main Stack | Sinter Machine | 1.75 | (3.85) | 81.0 |
| Flue to Zinc Stack | Zinc Fuming Furnace | 0.2 | (0.44) | 9.3 |
| Baghouse 1 | Blast Furnace,<br>Dross Reverb Furnace,<br>Ventilation | 0.07 | (0.15) | 3.2 |
| Baghouse 2 | Blast Furnace,<br>Dross Reverb Furnace,<br>Ventilation | 0.08 | (0.18) | 3.7 |
| Baghouse 3 | Blast Furnace,<br>Dross Reverb Furnace,<br>Ventilation | 0.06 | (0.13) | 2.8 |

## TABLE 4-4. MEASURED TOTAL PARTICULATE, LEAD, AND ARSENIC FUGITIVE EMISSION RATES AT THE ASARCO/EAST HELENA LEAD SMELTER[12]

| Operations | Total Particulate: Fugitive Particulate Emission Rate kg/hr | Total Particulate: Fugitive Particulate Emission Rate (lb/hr) | Total Particulate: % of Total Fugitive Particulate Emissions | Lead: Fugitive Lead Emission Rate kg/hr | Lead: Fugitive Lead Emission Rate (lb/hr) | Lead: % of Total Fugitive Lead Emissions | Arsenic: Fugitive Arsenic Emission Rate kg/hr | Arsenic: Fugitive Arsenic Emission Rate (lb/hr) | Arsenic: % of Total Fugitive Arsenic Emissions |
|---|---|---|---|---|---|---|---|---|---|
| Sinter Building | 1.22 | (2.7) | 14.5 | 0.12 | (0.3) | 7.7 | 0.01 | (0.02) | 1.6 |
| Dross/Reverb Building | 5.66 | (12.5) | 67.1 | 1.26 | (2.8) | 82.0 | 0.57 | (1.3) | 96.2 |
| Blast Furance | 0.66 | (1.5) | 7.8 | 0.07 | (0.2) | 4.6 | 0.01 | (0.02) | 1.7 |
| Zinc Fuming Facility | 0.26 | (0.6) | 3.1 | 0.03 | (0.06) | 1.8 | 0.001 | (0.002) | 0.2 |
| Zinc Furnace | 0.64 | (1.4) | 7.5 | 0.06 | (0.13) | 3.9 | 0.002 | (0.004) | 0.3 |
| Total for Entire Plant | 8.44 | (18.6) | 100.0 | 1.54 | (3.4) | 100.0 | 0.60 | (1.3) | 100.0 |

## TABLE 4-5. MEASURED TOTAL PARTICULATE, LEAD, AND ARSENIC FUGITIVE RATES AT THE ASARCO/GLOVER LEAD SMELTER[12]

| Operations | Total Particulate |  |  | Lead |  |  | Arsenic |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | Fugitive Particulate Emission Rate kg/hr | (lb/hr) | % of Total Fugitive Particulate Emissions | Fugitive Lead Emission Rate kg/hr | (lb/hr) | % of Total Fugitive Lead Emissions | Fugitive Arsenic Emission Rate kg/hr | (lb/hr) | % of Total Fugitive Arsenic Emissions |
| Sinter Building | 2.30 | (5.1) | 48.2 | 0.8 | (1.8) | 38.8 | 0.0008 | (0.002) | 16 |
| Blast Furnace | 2.33 | (5.1) | 48.6 | 1.19 | (2.6) | 57.7 | 0.0041 | (0.01) | 84 |
| Ore Storage Bins | 0.16 | (0.35) | 3.2 | 0.07 | (0.15) | 3.5 | Negligible |  | Negligible |
| Entire Plant Total | 4.79 | (10.6) | 100.0 | 2.06 | (4.5) | 100.0 | 0.005 |  | 100.0 |

the lead sintering operation. The $SO_2$ concentrations of the remaining offgas streams at primary lead smelters are too low to make contact sulfuric acid plants a viable EBC option for these streams. Fabric filter systems operated 10° to 25°C above the acid dewpoint of the gas stream are recommended as arsenic EBC for offgases generated by blast furnace, dross furnace, zinc fuming furnace, and lead refining processes. Information concerning the acid dewpoints of these streams is unavailable, but current practice in the primary lead smelting industry supports the feasibility of operating the fabric filter unit over the temperature range 100 to 125°C (212 to 260°F) with no deleterious effects due to corrosion.

Arsenic EBC for fugitive emissions in the primary lead smelting industry consists of enclosing of ore storage areas, ventilating and/or enclosing material transfer points, ventilating and/or enclosing furnace operations, and treating all of the ventilation gas streams with fabric filter systems. The specific techniques to be applied will vary on a plant-by-plant basis due to the diversity within the lead smelting industry.

### 4.3.2 Prevalence of Arsenic EBC Under the Baseline Level of Control

Arsenic EBC is in place for process emission sources at each of the five domestic primary lead smelters. The application of EBC for process sources has been motivated by existing $SO_2$ and particulate SIP emission limitations. Arsenic EBC for fugitive emissions are projected to be in place when compliance with the OSHA arsenic and lead standards and the impending SIP emission limitations for lead are achieved. Thus, there are no incremental environmental, energy, or economic impacts associated with the requirement of arsenic EBC for the primary lead smelting industry.

## 4.4 POPULATION EXPOSURE DATA

The data in Table 4-6 were developed during this study for use in an air pollution dispersion model to estimate the population exposure to arsenic from primary lead smelters. The Strategies and Air Standards Division (SASD) of EPA is using these data in an ongoing effort to estimate exposure to arsenic from this source category.

## 4.5 EASE OF STANDARDS DEVELOPMENT

Process arsenic emission sources at the five domestic primary lead smelters are currently controlled at the recommended EBC level. As discussed in Section 4.3, existing regulations for the control of $SO_2$ and particulate have resulted in lead smelters installing control systems that have the secondary benefit of effective arsenic removal.

The majority of fugitive arsenic emission sources at the primary lead smelters are not currently controlled by EBC. However, industry compliance with the OSHA lead and inorganic arsenic standards and the lead SIP's for the lead NAAQS attainment is projected to result in EBC for fugitive sources

## TABLE 4-6. POPULATION EXPOSURE MODELLING INPUT DATA FOR THE PRIMARY LEAD SMELTING INDUSTRY

| PLANT LOCATION | UTM COORDINATES (km) | EMISSION POINT | STACK PARAMETERS | | | | | ARSENIC EMISSIONS | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Height m (ft) | Diameter m (ft) | Exit Temp. °K (°F) | Flow Rate $m^3$/sec (acfm) | Flow Velocity m/sec (ft/sec) | Best Estimate kg/hr (lb/hr) | High Estimate kg/hr (lb/hr) |
| ASARCO | Zone 12 | Sinter/AP Stack | 61.0 (200)[17] | 1.7 (5.5)[14] | 377 (220)[14] | 20.8 (44,000)[14] | 9.2 (30.1)[14] | Negligible by Comparison | Negligible by Comparison[11] |
| East Helena, | Hor 429.5 km | Sinter/FF Stack | 128.0 (420)[14] | 2.7 (9.0)[14] | 352 (175)[14] | 94.5 (200,000)[14] | 16.5 (54.1)[14] | 1.75 (3.85)[11] | 1.75 (3.85)[11] |
| MT | Vert 5158.8 km | Blast/Rev Stack | 129.6 (425)[14] | 3.0 (10.0)[14] | 330 (135)[14] | 142 (300,000)[14] | 19.4 (63.7)[14] | 0.2 (0.44)[11] | 0.2 (0.44)[11] |
| | | Zn Fume Stack | 122.0 (400)[14] | 3.4 (11.2)[14] | 375 (215)[14] | 107 (226,000)[14] | 11.7 (38.2)[14] | 0.2 (0.43)[11] | 0.2 (0.43)[11] |
| | | Total Fugitives | | | | | | 0.6 (1.30)[12] | 0.6 (1.30)[12] |
| ASARCO | Zone | Sinter/AP Stack | 40 (131)[15] | 2.7 (8.9)[15] | 337 (147)[15] | 17.2 (36,000)[15] | 8.0 (26.2)[15] | Negligible by Comparison | Negligible by Comparison |
| El Paso, TX | Hor 346.3 | Blast/Rev Stack | 186 (610)[15] | 4.3 (14.1)[15] | 345 (162)[15] | 247 (520,000)[15] | 17.0 (55.8)[15] | 0.2 (0.44)[16] | 0.2 (0.44)[16] |
| | Vert 3517.5 | Zn Fuming Furn. Stack | 91 (300)[15] | 4.9 (16.1)[15] | 330 (135)[15] | 56.6 (120,000)[15] | 3.0 (9.8)[15] | 0.2 (0.44)[16] | 0.2 (0.44)[16] |
| | | Total Fugitives | | | | | | 0.6 (1.30)[16] | 0.6 (1.30)[16] |
| St. Joe | Zone 15 | Sinter/Blast/ Reverb Stack | 107.3 (352)[15] | 6.1 (20.0)[15] | 353 (176)[15] | 395 (835,000)[15] | 13.5 (44.3)[15] | 0.33 (0.72)[16] | 1.12 (2.47)[16] |
| Herculaneum, MO | Hor 729.0 km<br>Vert 4238.0 km | Total Fugitives | | | | | | 0.01 (0.021)[16] | 0.075 (0.165)[16] |
| ASARCO | Zone 15 | Main Stack | 185.9 (610)[15] | 3.2 (10.4)[17] | 375 (216)[15] | 110 (230,000)[17] | 13.7 (45.0)[17] | | |
| Glover, MO | Hor 706.8 | Baghouse Stack | 28.8 (78.0)[17] | 1.5 (5.0)[17] | 294 (70)[15] | 33 (70,000)[17] | 16.8 (55.0)[17] | | |
| | Vert 4041.2 | Venturi Stack | 23.8 (78.0)[17] | 1.5 (5.0)[17] | 294 (70)[15] | 35 (75,000)[17] | 18.3 (60.0)[17] | 0.20 (0.44)[16] | 0.55 (1.21)[16] |
| | | Blast Furn. Stack | 114 (375)[17] | 2.1 (7.0)[17] | 333 (140)[17] | 31 (165,000)[17] | 21.3 (70)[17] | | |
| | | Total Fugitives | | | | | | 0.005 (0.01)[12] | 0.005 (0.01)[12] |
| AMAX | Zone 15 | Main Stack | 61.0 (200)[15] | 4.6 (15.1)[15] | 355 (180)[15] | 166 (350,000)[15] | 10.0 (32.8)[15] | 0.20 (0.44)[16] | 0.72 (1.59)[16] |
| Boss, MO | Hor 659.4 | AP Stack | 30.5 (100)[15] | 1.0 (3.3)[15] | 300 (80.6)[15] | 104 (220,000)[15] | 13.3 (43.6)[15] | Negligible by Comparison | Negligible by Comparison[16] |
| | Vert 4167.4 | Total Fugitives | | | | | | 0.006 (0.013)[16] | 0.063 (0.139)[16] |

also being in place. The data are not available to accurately estimate when all fugitive sources will be at EBC.

Thus, compliance with existing regulations will result in the application of arsenic EBC for both process and fugitive sources in the primary lead smelting industry. Arsenic emissions standards development would have a negligible inpact on the industry.

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# 5.0 PRIMARY ZINC SMELTING

This chapter discusses the primary zinc smelting industry and its associated arsenic emissions. Section 5.1 presents a brief source category description. Section 5.2 discusses the regulations currently covering the industry and the resulting level of control and associated arsenic emissions. Section 5.3 presents a discussion of the EBC options and Section 5.4 discusses the impacts of applying these options. Section 5.5 presents the input data to be used in assessing the population exposure to arsenic emissions from primary zinc metal smelting and zinc oxide production. The ease of standards development is discussed in Section 5.6.

## 5.1 PRIMARY ZINC SMELTING DESCRIPTION

Metallic zinc is produced from zinc ore concentrates at primary zinc smelters. The estimated domestic production of primary slab zinc in 1978 was 407,000 Mg (448,000 tons),[1] which accounted for approximately 49 percent of the total U. S. demand for primary zinc metal. There are currently five plants that produce primary zinc in the United States. In addition, two zinc oxide plants have been considered in this study because they produce zinc oxide directly from zinc ore concentrates and thus are sources of inorganic arsenic emissions. Table 5-1 lists the names, locations, production capacities, and estimated inorganic arsenic emission rates of the plants. The total annual inorganic arsenic emission rate from the five primary zinc metal smelters is estimated to be about 0.3 Mg (0.3 tons) arsenic/year. Annual arsenic emissions from the two zinc oxide plants are estimated to be 5.2 Mg (5.7 tons)/yr.

There are two major types of primary zinc metal production facilities, pyrometallurgical smelters and electrolytic plants. The only domestic pyrometallurgical primary zinc metal smelter operation is the St. Joe Minerals electrothermal smelter in Monaca, Pennsylvania. During the last few decades, electrolytic zinc plants have achieved predominance over pyrometallurgical zinc smelters in the domestic primary zinc industry. Four of the five U. S. primary zinc metal plants are electrolytic facilities.

The materials processed by the domestic primary zinc industry are predominantly sulfide ore concentrates. The most common zinc-bearing constituent of these ores is sphalerite (ZnS). Raw zinc ores are treated at the mine site with flotation techniques to produce a concentrate containing up to 62 percent zinc and 32 percent sulfur. Other zinc ore constituents include iron, calcium, silicon, lead, magnesium, cadmium, copper, aluminum, cobalt, and arsenic. The arsenic content of the ore concentrates processed in the domestic zinc smelting industry range from about 0.001 to 0.100 percent by weight. A U. S. Bureau of Mines Publication lists the

## TABLE 5-1. THE PRIMARY ZINC SMELTING INDUSTRY

| PLANT/LOCATION | PLANT TYPE | PRODUCTION CAPACITY Mg/yr | PRODUCTION CAPACITY (tons/yr) | ESTIMATED BASELINE INORGANIC ARSENIC EMISSIONS[a] kg/hr | ESTIMATED BASELINE INORGANIC ARSENIC EMISSIONS[a] (lb/hr) |
|---|---|---|---|---|---|
| St. Joe/ Monaca, PA | Electrothermal Zinc/Zinc Oxide Smelter | 30,000 | (33,000) | 0.023 | (0.051) |
| ASARCO/ Corpus Christi, TX | Electrolytic Zinc Plant | 98,000 | (110,000) | 0.0014 | (0.0031) |
| AMAX/ Sauget, IL | Electrolytic Zinc Plant | 76,000 | (84,000) | 0.0028 | (0.0062) |
| Jersey Miniere Zinc/ Clarksville, TN | Electrolytic Zinc Plant | 82,000 | (90,000) | 0.0030 | (0.0067) |
| National Zinc/ Bartlesville, OK | Electrolytic Zinc Plant | 51,000 | (56,000) | 0.0014 | (0.0031) |
| ASARCO/ Columbus, OH | American Process Zinc Oxide Smelter | 20,000[b] | (22,000) | 0.014 | (0.031) |
| New Jersey Zinc/ Palmerton, PA | American Process Zinc Oxide Smelter | 30,000[b] | (33,000) | 0.60 | (1.3) |

[a] The arsenic emissions estimates shown represent a "best estimate" of baseline emissions. See Appendix A for development of estimates.

[b] Production capacity of zinc oxide (ZnO).

average arsenic content of zinc ore concentrates processed in the electrolytic portion of the industry as 0.07 percent by weight.[2] Table 5-2 includes the arsenic content of the zinc ore concentrates processed at several domestic facilities.

The first step in the production of zinc metal from ore concentrates at both electrolytic and pyrometallurgical zinc smelters is the roasting operation. Zinc roasting consists of heating the ore concentrates to 650-1000°C (1200-1800°F) in an oxidizing environment. The roast is carried out below the melting temperature of the charge and has three primary functions: (i) elimination of sulfur as $SO_2$, (ii) conversion of zinc sulfide to impure zinc oxide, and (iii) removal of volatile impurities from the ore concentrate. The degree of sulfur elimination accomplished in a zinc roaster varies from about 93 to 97 percent.[3]

The fluid bed roaster is the newest roasting system for zinc sulfide concentrates and is currently the only type in use. The offgas stream from a zinc roaster typically has an $SO_2$ concentration of 10 to 13 percent, and up to 85 percent of the roaster product (calcine) is carried out with the offgas. Waste heat boilers, cyclones, and electrostatic precipitators are used in series to capture the entrained portion of the calcine. The collected materials are normally combined with the remaining portion of the calcine and sent to either a sinter machine (pyrometallurgical smelting facility) or a leaching plant (electrolytic facility). Contact sulfuric acid plants are used for $SO_2$ control at all of the fluid bed roasters within the primary zinc industry.[2] Figure 5-1 illustrates the fluid bed roasting system at the Jersey Miniere Zinc electrolytic zinc plant in Clarksville, Tennessee.

### 5.1.1 Electrothermal Zinc Smelting

The roasting operation and the remaining steps in the production of zinc metal at the St. Joe/Monaca electrothermal zinc smelter are shown in Figure 5-2. The roaster calcine is first mixed and pelletized with sand, return sinter fines, coke breeze, and smelting furnace residue. The pelletized mixture is distributed on grate-type pallets that move along a continuous metal conveyor system within the sinter machine. The purpose of the sintering operation is to remove residual sulfur and volatile impurities such as lead, cadmium, and arsenic from the calcine, and to agglomerate the feed for reduction in the electrothermal smelting furnace. Sinter offgases typically contain about 0.1 percent $SO_2$. Low-temperature baghouse units operated at about 93°C (200°F) are used for particulate control.

The sinter product is sent to the electrothermal furnace, where the zinc content of the zinc oxide/coke/silica mixture is separated and reduced to pure zinc metal. Heat is produced within the furnace by the resistance of the charge material to the current flow between pairs of graphite electrodes. The zinc metal produced is vaporized in the high temperature atmosphere of the furnace (1400°C or 2600°F). Furnace vapors are drawn

## TABLE 5-2. THE ARSENIC CONTENT OF THE ZINC ORE CONCENTRATES AT SEVERAL DOMESTIC PRIMARY ZINC SMELTERS

| PLANT | ARSENIC CONTENT OF ORE CONCENTRATE (WEIGHT PERCENT) |
|---|---|
| National Zinc/Bartlesville, Oklahoma[a] | < 0.1 |
| St. Joe/Monaca, Pennsylvania[b] | 0.005 |
| Jersey Miniere Zinc/Clarksville, Tennessee[c] | 0.0018 |
| New Jersey Zinc/Palmerton, Pennsylvania[d,e] | 0.08 - 0.13 |
| ASARCO/Corpus Christi, Texas[f] | 0.001 |

[a] Telecon. L. R. Meadows, National Zinc, with Larry Keller, Radian Corporation. January 22, 1982.

[b] Telecon. Thomas Janeck, St. Joe Minerals Corporation, with Larry Keller, Radian Corporation. February 11, 1982.

[c] Painter, L. A., "Jersey Miniere Zinc: Plant Design and Start-Up." Engineering and Mining Journal, July 1980.

[d] Telecon. Maurice Silvestris, New Jersey Zinc, with Larry Keller, Radian Corporation. January 22, 1982.

[e] The ore smelted at the New Jersey Zinc/Palmerton facility is unique in that it is a low-sulfur ore (Ogdensburg ore).

[f] Telecon. Ken Nelson, ASARCO, with Larry Keller, Radian Corporation. March 2, 1982.

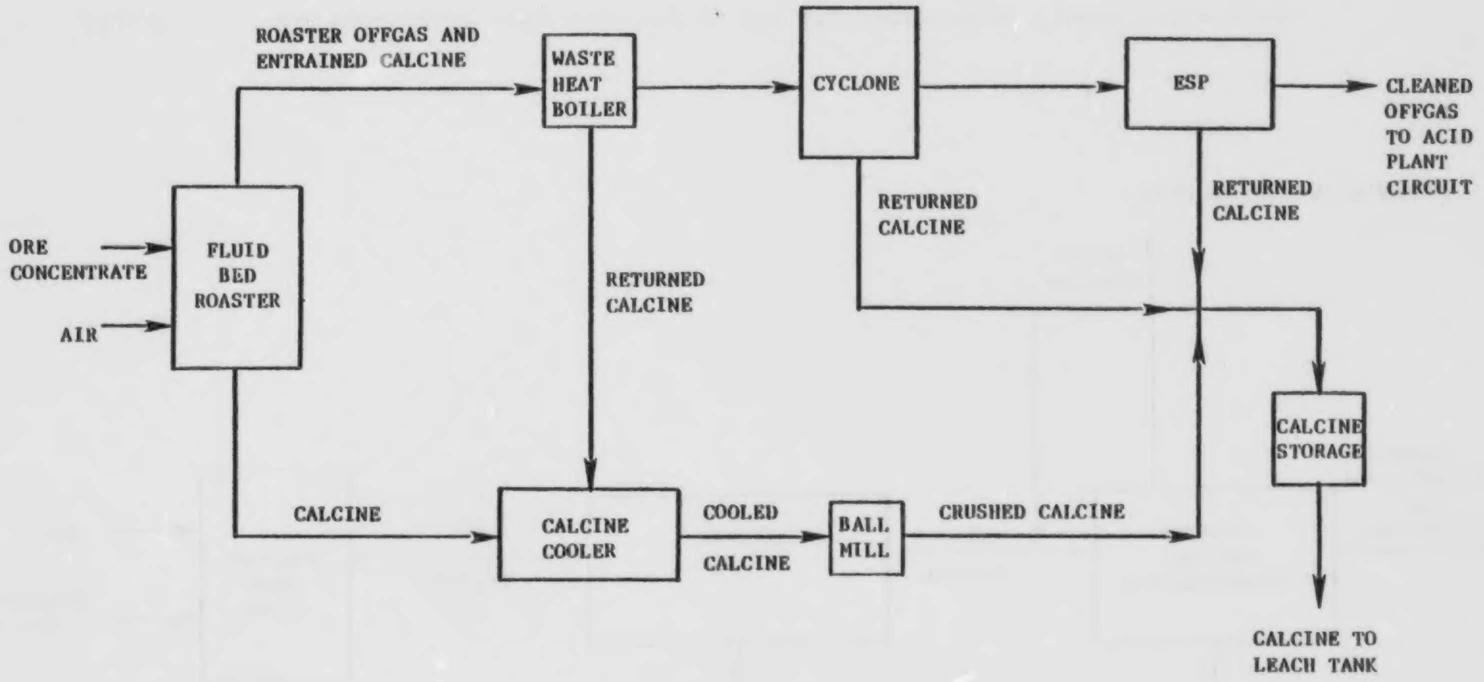
ROASTER OFFGAS AND ENTRAINED CALCINE
WASTE HEAT BOILER
CYCLONE
ESP
CLEANED OFFGAS TO ACID PLANT CIRCUIT
ORE CONCENTRATE
AIR
FLUID BED ROASTER
RETURNED CALCINE
RETURNED CALCINE
RETURNED CALCINE
CALCINE STORAGE
CALCINE
CALCINE COOLER
COOLED CALCINE
BALL MILL
CRUSHED CALCINE
CALCINE TO LEACH TANK

Figure 5-1. Fluid bed roasting system at the Jersey Miniere Electrolytic Zinc plant in Clarksville, Tennessee.

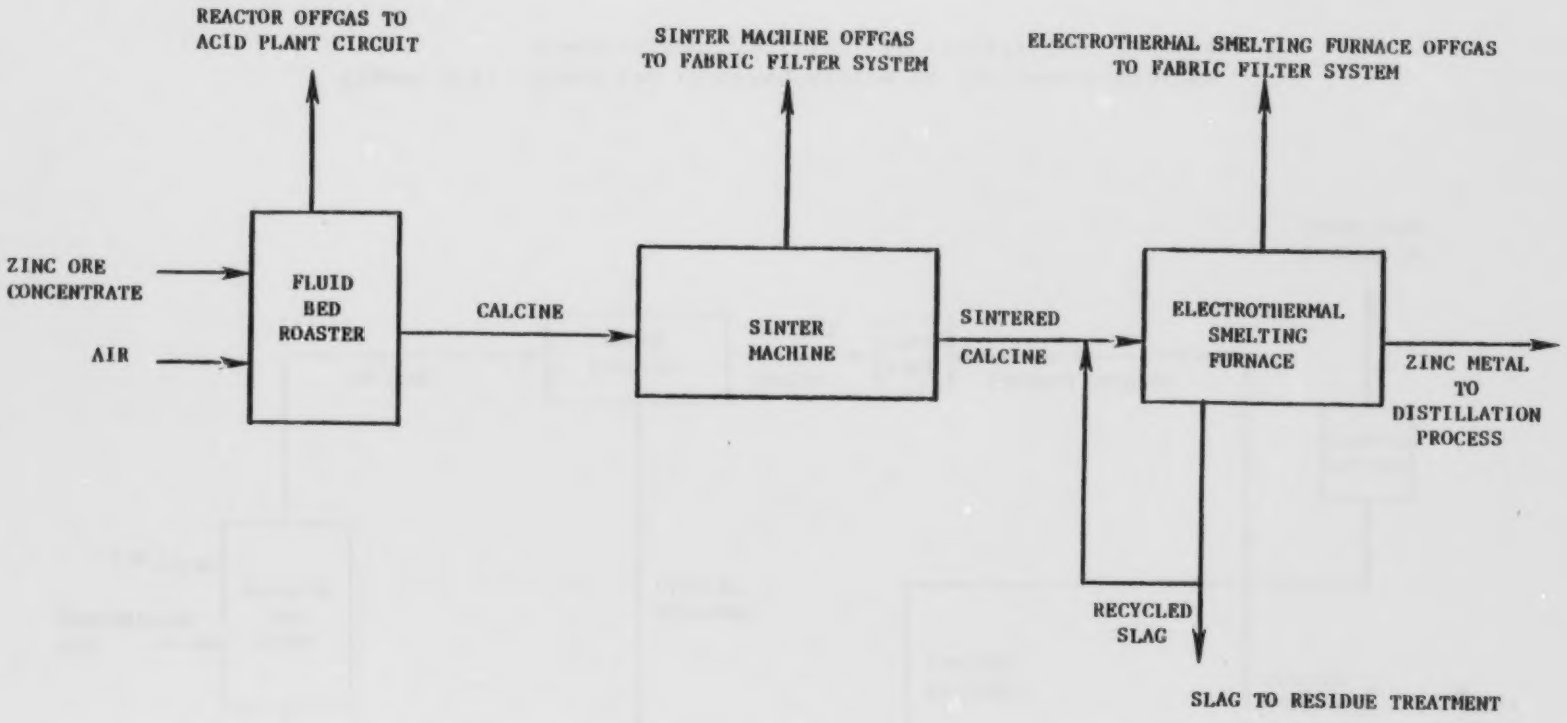
REACTOR OFFGAS TO ACID PLANT CIRCUIT
SINTER MACHINE OFFGAS TO FABRIC FILTER SYSTEM
ELECTROTHERMAL SMELTING FURNACE OFFGAS TO FABRIC FILTER SYSTEM
ZINC ORE CONCENTRATE
AIR
FLUID BED ROASTER
CALCINE
SINTER MACHINE
SINTERED CALCINE
ELECTROTHERMAL SMELTING FURNACE
ZINC METAL TO DISTILLATION PROCESS
RECYCLED SLAG
SLAG TO RESIDUE TREATMENT

Figure 5-2. Electrothermal zinc smelting at the St. Joe/Monaca, Pennsylvania plant.

through a water cooled, U-shaped condenser and bubbled through a molten zinc bath. The zinc metal vapor condenses and is subsequently cast into slabs. Offgases from the electrothermal furnace are treated for particulate removal by baghouse units operated at about 93°C (200°F). Fugitive emission controls at the St. Joe/Monaca facility consist of local ventilation of all materials handling systems followed by particulate collection in fabric filter units. Table 5-3 contains a summary of the existing air pollution control equipment at St. Joe/Monaca.

Arsenic elimination can be achieved by several mechanisms in the electrothermal smelting of zinc. Arsenic can be volatilized as arsenic trioxide ($As_2O_3$) from the roaster, the sinter machine, or the electrothermal furnace, and it can be slagged from the electrothermal furnace. Data presented in a U. S. Bureau of Mines publication suggests that the largest single source of arsenic elimination from pyrometallurgical smelters is the furnace slag.[2]

### 5.1.2 Electrolytic Zinc Production

The roasting operation and the remaining steps in the production of zinc metal at a typical electrolytic zinc smelter are shown in Figure 5-3. The roaster calcine is first leached in a dilute sulfuric acid solution to dissolve the impure zinc oxide. Manganese dioxide ($MnO_2$) is generally added to the leach tank to cause the precipitation of an iron cake that contains iron and significant amounts of arsenic, antimony, and silicic acid. The leachate is then sent to a series of cold and hot purification tanks where cadmium, copper, and cobalt are removed from solution. The precipitation reactions that occur are induced by the addition of zinc dust, which reduces $Cd^{+2}$, $Cu^{+2}$, and $Co^{+2}$ to their respective metallic forms. At least one domestic primary zinc smelter utilizes arsenic trioxide as an activating reagent in the removal of cobalt from the zinc-bearing solution.[4]

The final step in the electrolytic production of zinc metal is electrodeposition onto the surface of the cell house electrodes. An electric potential is applied to the solution, causing the formation of zinc metal and sulfuric acid. The sulfuric acid is recycled to the leach tank, and the zinc metal is stripped from the electrodes and cast into slabs.

The fluid bed roaster $SO_2$ emissions at each of the four domestic electrolytic zinc smelters are controlled by a contact sulfuric acid plant. The remaining steps in the electrolytic production of zinc do not generate significant amounts of atmospheric emissions. Demisters are used to control acid mist from the cell house operations.

Data on the distribution of arsenic at electrolytic zinc smelters are presented in reference 2. Although the information given is incomplete, the largest source of arsenic elimination is shown to be the leach residues. Most of the arsenic entering an electrolytic zinc plant is removed in the solid or liquid phase with the iron and copper cakes.

TABLE 5-3. EXISTING AIR POLLUTION CONTROL EQUIPMENT AT THE ST. JOE/MONACA ELECTROTHERMAL ZINC SMELTER

| EMISSION SOURCE | EXISTING AIR POLLUTION CONTROL EQUIPMENT |
|---|---|
| Ore Concentrate Dryer | Venturi Scrubber |
| Fluid Bed Roaster | Cyclone/ESP/Contact Sulfuric Acid Plant |
| Sinter Machine | Fabric Filter (93°C) (200°F) |
| Sinter Sizing & Crushing | Fabric Filter (93°C) (200°F) |
| Electrothermal Furnace | Fabric Filter (93°C) (200°F) |

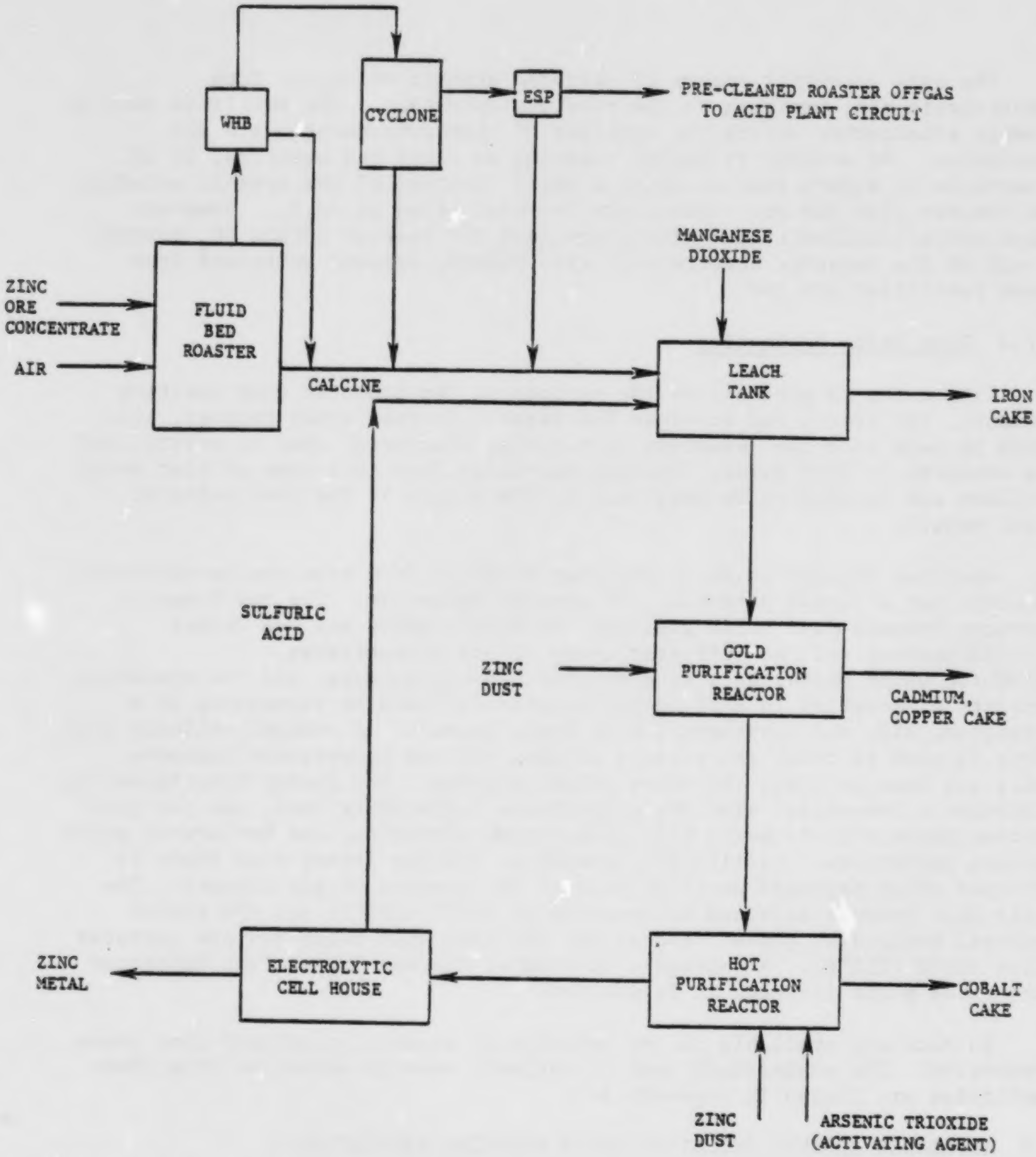
WHB
CYCLONE
ESP
PRE-CLEANED ROASTER OFFGAS
TO ACID PLANT CIRCUIT
MANGANESE
DIOXIDE
ZINC
ORE
CONCENTRATE
AIR
FLUID
BED
ROASTER
CALCINE
LEACH
TANK
IRON
CAKE
SULFURIC
ACID
ZINC
DUST
COLD
PURIFICATION
REACTOR
CADMIUM,
COPPER CAKE
ZINC
METAL
ELECTROLYTIC
CELL HOUSE
HOT
PURIFICATION
REACTOR
COBALT
CAKE
ZINC
DUST
ARSENIC TRIOXIDE
(ACTIVATING AGENT)

Figure 5-3. A typical electrolytic zinc smelter.

The only potential source of airborne arsenic emissions from electrolytic zinc smelting is the roasting operation. The available data on arsenic elimination during the roasting of zinc concentrates are not conclusive. By analogy to copper roasting in fluid bed roasters, it is reasonable to expect that at least a small fraction of the arsenic entering the roaster with the ore concentrate is volatilized as $As_2O_3$. However, since contact sulfuric acid plants are used for roaster offgas $SO_2$ control at all of the domestic electrolytic zinc plants, arsenic emissions from these facilities are low.

### 5.1.3 Zinc Oxide Production

Zinc oxide is produced by two methods in the domestic zinc smelting industry, the French and American Processes. In the French Process, zinc oxide is made from the oxidation of purified zinc metal that is volatilized and oxidized to zinc oxide. Arsenic emissions from this type of zinc oxide facility are assumed to be small due to the purity of the feed material (zinc metal).

American Process oxide is produced directly from zinc ore concentrates, and thus has a larger potential for arsenic emissions. The two domestic American Process zinc oxide smelters (ASARCO/Columbus and New Jersey Zinc/Palmerton) utilize different types of ore concentrates. ASARCO/Columbus processes a zinc sulfide ore concentrate, and the operation consists of roasting in a fluid bed roaster followed by processing in a densifying kiln and a wetherill zinc oxide furnace. A contact sulfuric acid plant is used to treat the roaster offgas, and low temperature baghouse units are used to treat the other offgas streams. New Jersey Zinc/Palmerton processes a low-sulfur zinc ore concentrate (Ogdensburg ore), and the major process steps include waelz kiln operations, sintering, and horizontal grate furnace operations. Particulate removal at the New Jersey zinc plant is achieved using baghouse units on each of the process offgas streams. The waelz kiln product baghouse is operated at 140°C (280°F) and the sinter machine, horizontal grate furnace, and the fume kiln baghouses are operated below 100°C (212°F). A schematic diagram of the New Jersey Zinc/Palmerton zinc oxide plant is shown in Figure 5-4.

No data are available on the behavior of arsenic in primary zinc oxide production. The assumptions used to estimate arsenic emissions from these facilities are listed in Appendix A-5.

## 5.2 INORGANIC ARSENIC EMISSIONS UNDER EXISTING REGULATIONS

### 5.2.1 Regulatory Impacts

The existing regulations affecting the primary zinc smelting industry are the $SO_2$ and particulate matter NSPS, the $SO_2$ and particulate matter SIP emission limitations, and the OSHA inorganic arsenic workplace standard. All of the primary zinc smelters are in compliance with their respective

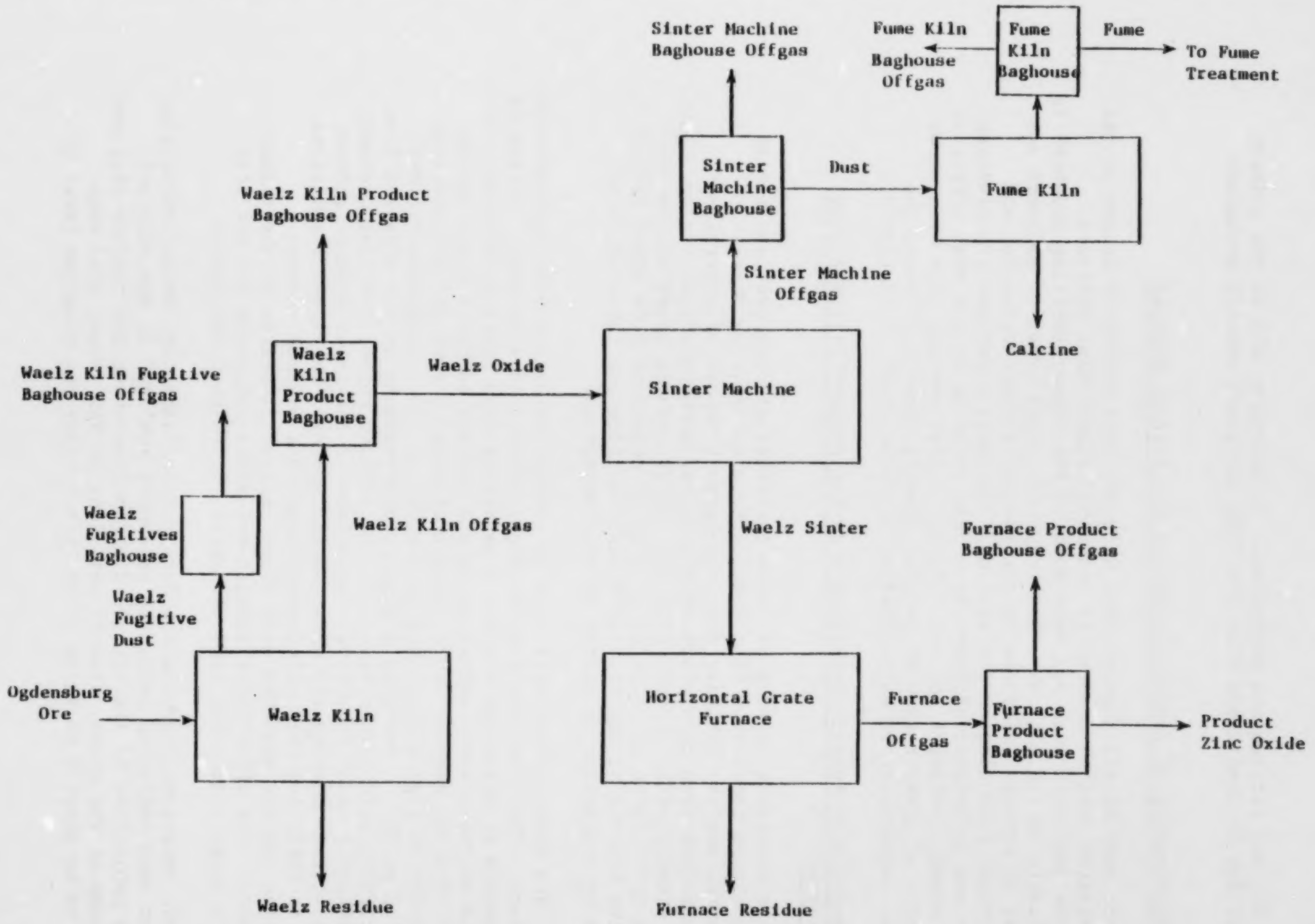
Sinter Machine Baghouse Offgas
Fume Kiln Baghouse Offgas
Fume Kiln Baghouse
Fume
To Fume Treatment
Sinter Machine Baghouse
Dust
Fume Kiln
Waelz Kiln Product Baghouse Offgas
Sinter Machine Offgas
Calcine
Waelz Kiln Fugitive Baghouse Offgas
Waelz Kiln Product Baghouse
Waelz Oxide
Sinter Machine
Waelz Fugitives Baghouse
Waelz Kiln Offgas
Waelz Sinter
Furnace Product Baghouse Offgas
Waelz Fugitive Dust
Ogdensburg Ore
Waelz Kiln
Horizontal Grate Furnace
Furnace Offgas
Furnace Product Baghouse
Product Zinc Oxide
Waelz Residue
Furnace Residue

Figure 5-4. The New Jersey Zinc/Palmerton zinc oxide plant.

SIP's for $SO_2$ and particulate emissions. In addition, all of the primary zinc plants are in compliance with the OSHA inorganic arsenic workplace standard.

### 5.2.2 Effectiveness of Existing Controls for Arsenic Removal

Arsenic removal efficiency tests have not been conducted on any of the process emission control systems at existing primary zinc smelters. However, the test work that has been done in the copper smelting industry is also applicable to the zinc smelting industry. Both types of smelters are hot sources of arsenic emissions in the form of arsenic trioxide, and similar control technologies are applied. The acid plant/gas pre-cleaning systems in use on roaster offgases have been shown to be the most effective method of arsenic emission control. Fabric filter systems have been shown to be capable of greater than 90 percent arsenic removal provided the operational temperature is maintained at or below about 110°C (230°F).

### 5.2.3 Magnitude of Arsenic Emissions from the Primary Zinc Smelting Industry

Arsenic emissions testing has been performed at only one facility in the zinc smelting industry. Test results from the St. Joe/Monaca electrothermal smelter indicate that the largest source of controlled arsenic emissions from that plant is the sinter machine offgas stream. The estimated arsenic emission rate from the sinter machine based on the test results is 0.023 kg/hr (0.05 lb/hr). Arsenic emissions from other process and fugitive sources at the St. Joe/Monaca facility are reported to be negligible in comparison to sinter machine emissions.[5]

There has been no test work done on arsenic emissions from electrolytic zinc smelters. The fluid bed roaster/contact sulfuric acid plant tailgas is the only source of appreciable arsenic emissions from these facilities. An upper bound on the arsenic emissions from a contact sulfuric plant can be calculated from the maximum concentration of arsenic that can be tolerated as an impurity to the catalyst bed in the $SO_2 \rightleftarrows SO_3$ conversion process, which is 1.2 mg/Nm$^3$.[6] Measured arsenic concentrations in the offgases from contact sulfuric acid plants tested in the primary copper smelting industry were consistently below this level regardless of the inlet arsenic content of the gas stream entering the pre-cleaning system. The arsenic emissions estimates in Table 5-4 were calculated using this maximum arsenic concentration and the measured acid plant tailgas flowrates in the primary zinc industry. The upper bound arsenic emissions estimates for the acid plant units range from 0.022 to 0.047 kg/hr (0.010 to 0.048 lb/hr).

Arsenic emissions from the New Jersey Zinc/Palmerton, Pennsylvania zinc oxide plant were estimated using the procedure outlined in Appendix A-5. Based on a projection of the arsenic distribution among the various slag and vapor streams at the plant, arsenic emissions at New Jersey zinc were estimated to be about 0.60 kg/hr (1.33 lb/hr) under the baseline level of

## TABLE 5-4. UPPER-BOUND ESTIMATES OF INORGANIC ARSENIC EMISSIONS FROM CONTACT SULFURIC ACID PLANTS IN THE PRIMARY ZINC SMELTING INDUSTRY

| PLANT/LOCATION | MAXIMUM INORGANIC ARSENIC EMISSION RATE FROM CONTACT SULFURIC ACID PLANT[a] kg/hr | (lb/hr) |
|---|---|---|
| ASARCO/Corpus Christi, TX | 0.023 | (0.051) |
| AMAX/Sauget, IL | 0.045 | (0.099) |
| Jersey Miniere Zinc/Clarksville, TN | 0.047 | (0.10) |
| National Zinc/Bartlesville, OK | 0.023 | (0.051) |
| ASARCO/Columbus, OH | 0.022 | (0.048) |

[a] Estimates made based on maximum permissible arsenic impurity limits for acid plant feed gas (1.2 mg/Nm$^3$).

control. However, no arsenic emission test data are available for comparison purposes to verify the estimate.

## 5.3 ARSENIC EBC OPTIONS FOR THE PRIMARY ZINC INDUSTRY

### 5.3.1 Definition of Arsenic EBC

Arsenic EBC for primary zinc plants is defined by analogy to arsenic EBC in the primary copper smelting industry. Contact sulfuric acid plants and the associated gas pre-cleaning systems are recommended for the treatment of offgas streams containing sufficient $SO_2$ such as those produced by fluid bed roasters. The $SO_2$ levels of the remaining offgas streams at primary zinc and primary zinc oxide smelters are too low to make contact sulfuric acid plants a viable EBC option for these streams. Fabric filter systems operated 10° to 25°C above the best estimate of the acid dew point of the gas stream are recommended as arsenic EBC for offgas streams low in $SO_2$ content. Operations controlled in this manner include the sinter machine and the electrothermal furnace offgases at St. Joe/Monaca, and the Waelz kiln, sinter machine, horizontal moving grate furnace, and fume kiln offgases at New Jersey Zinc/Palmerton. An operational temperature below 110°C (230°F) is suggested by analogy to the available data in the primary copper smelting industry.

Arsenic fugitive EBC in the primary zinc smelting industry consists of the best available ventilation technology for each fugitive arsenic emission source followed by particulate removal in a fabric filter system operated below 110°C (230°F). This includes enclosure of ore storage areas, ventilating and/or enclosing material transfer points, properly ventilating and/or enclosing all furnace operations, and treating all of the ventilation gas streams with fabric filter systems. The specific techniques constituting arsenic fugitive EBC will vary from plant to plant due to the diversity of plant types within the primary zinc smelting industry.

### 5.3.2 Prevalence of Arsenic EBC

Arsenic EBC is in place for all arsenic emission sources at the electrothermal and electrolytic primary zinc metal plants and at the ASARCO/Columbus zinc oxide plant. In addition, all arsenic emission sources at the New Jersey Zinc/Palmerton zinc oxide smelter are controlled at the EBC level except for the waelz kiln offgas stream. The fabric filter system serving this stream is operated at 140°C (280°F), a relatively high temperature for effective arsenic capture. Arsenic EBC for this particular emission source consists of lowering the operational temperature of the fabric filter unit closer to the acid dew point of the gas stream. The acid dew point of the stream is likely to be low (below 100°C or 212°F) because the sulfur content of the ore concentrate smelted at New Jersey Zinc is very low and hence there will be little $SO_3$ in the offgas. The cooling capacity required to lower the temperature of the waelz kiln offgas stream could easily be provided by a water spray chamber system.

## 5.4 INCREMENTAL IMPACTS ASSOCIATED WITH THE ARSENIC EBC OPTIONS

The incremental impacts of the arsenic EBC options have been assessed for the only primary zinc smelter for which arsenic EBC is judged to be not fully in place (New Jersey Zinc/Palmerton zinc oxide plant). The environmental, energy, and economic impacts resulting from the EBC option are discussed in the following sections.

### 5.4.1 Environmental Impacts

The greatest environmental impact associated with the implementation of arsenic EBC in the primary zinc smelting industry would be the reduction of atmospheric arsenic emissions. It is estimated that arsenic emissions at the New Jersey Zinc facility will be reduced by 0.50 kg/hr (1.1 lb/hr) below the baseline emissions level. The methods used to obtain the emissions reduction estimate are presented in Appendix A-5.

The water and solid waste impacts associated with implementing arsenic EBC are minimal. No additional wastewater would be generated by the spray chamber operation. All cooling water would be evaporated in the spray chamber, leaving only a mud-like residue. This mud is then periodically disposed of in a secured landfill along with other smelter slags that cannot be recycled. From the standpoint of solid waste, the only other potential impact of EBC implementation would be an increase in the impurity content of the process slags generated at New Jersey Zinc due to enhanced recycling of volatilized materials. However, this effect has not been demonstrated and is not expected to significantly alter the disposal characteristics of the slags.

### 5.4.2 Energy Impact

The recommended EBC option would require that additional energy be consumed beyond that needed for baseline control. Additional energy would be used to operate the gas cooler/spray chamber system for the waelz kiln sinter offgas stream. The estimated annual power requirement of the cooling system is 75 Gj ($2 \times 10^4$ kWh).

### 5.4.3 Control Cost Impacts

The estimated capital and operating costs associated with the implementation of arsenic EBC at New Jersey Zinc are shown in Table 5-5. The total incremental annual cost in final quarter 1981 dollars associated with implementing arsenic EBC is estimated to be $112,000 per year. The methods used to obtain the cost estimates are summarized in Appendix B-5.

### 5.4.4 Economic Impact Resulting from EBC

An economic impact analysis was conducted for one zinc oxide plant to estimate the potential impact of requiring EBC. All other facilities in the

TABLE 5-5. TOTAL CAPITAL AND OPERATING COSTS ASSOCIATED WITH THE INSTALLATION OR ARSENIC EBC AT THE NEW JERSEY ZINC/PALMERTON ZINC OXIDE PLANT

| PLANT | PLANT CAPACITY (Mg/yr) | TOTAL BASELINE ARSENIC EMISSIONS (kg/hr) | CONTROL EQUIPMENT REQUIRED TO REACH ARSENIC EBC | ACHIEVABLE ARSENIC EMISSIONS REDUCTION RELATIVE TO BASELINE CONTROL (kg/hr) | INSTALLED TOTAL CAPITAL COST OF REQUIRED EQUIPMENT ($10^3$ $) | TOTAL ANNUALIZED COST OF REQUIRED EQUIPMENT ($10^3$ $/yr) | COST OF CONTROL PER Mg ARSENIC REMOVED ($/Mg) |
|---|---|---|---|---|---|---|---|
| New Jersey Zinc/ Palmerton, PA | 30,000 | 0.59 | Spray Chamber/ Cooling Capacity | 0.50 | 342 | 112.3 | $2.5 \times 10^4$ |
| Others | | | None | - | - | - | - |

[a] New Jersey Zinc plant capacity listed in Mg zinc oxide (ZnO) per year.

zinc smelting and zinc oxide industry were determined to have EBC in place. Using the cost data in Table 5-5 and the methodology given in Appendix C, revenue and product price increases, required by the plant to maintain the same net present values before and after the installation of EBC, were estimated. To test the sensitivity of the economic impact results to the various input data, a sensitivity analysis was conducted for the plant, assuming simultaneous 15 percent decreases in baseline price and annual output and a 15 percent increase in the weighted cost of capital.

The annual revenue increase required by the zinc oxide plant to maintain its profitability under EBC is slightly less than $100,000, which is equivalent to a product price increase of 0.3¢ per kg (0.14¢ per lb). The percentage increase in the product price is 0.3 percent.

Under the sensitivity conditions the analysis showed that the plant would incur a unit price increase of 0.4¢ per kg of product in order to maintain profitability. This price increase is equivalent to a percentage unit price increase of 0.4 percent. Table 5-6 summarizes the economic analysis results for the EBC and sensitivity cases.

## 5.5 POPULATION EXPOSURE DATA

The data in Table 5-7 were developed during this study for use in an air pollution dispersion model to estimate the population exposure to arsenic from primary zinc smelters. The Strategies and Air Standards Division (SASD) of EPA is using these data in an ongoing effort to estimate exposure to arsenic from this source category.

## 5.6 EASE OF STANDARDS DEVELOPMENT

The primary zinc smelting industry is predominantly controlled at the EBC level for arsenic emissions, and standards development would be likely to impact only one plant. There are no known technical impediments to the implementation of EBC at that plant. As discussed in Section 5.4.4, the economic impact of requiring EBC would cause a product price increase of 0.3 percent. Economic feasibility does not appear to be an impediment to EBC use at the zinc plant in question.

TABLE 5-6. REVENUE AND PRICE IMPACTS FOR PRIMARY ZINC CATEGORY

| MODEL PLANT | REQUIRED REVENUE INCREASE (000 dollars) | REQUIRED UNIT PRICE INCREASE (dollars per kg) | REQUIRED PERCENT PRICE INCREASE |
|---|---|---|---|
| EBC Case | 99.6 | .003 | 0.3 |
| Sensitivity Case | 104.6 | .004 | 0.4 |

## TABLE 5-7. POPULATION EXPOSURE MODELLING INPUT DATA FOR THE PRIMARY ZINC SMELTING INDUSTRY

| PLANT LOCATION | UTM COORDINATES (km) | EMISSION POINT | STACK PARAMETERS Height m (ft) | Diameter m (ft) | Exit Temp. °K (°F) | Flow Rate $m^3$/sec (acfm) | Flow Velocity m/sec (ft/sec) | ARSENIC EMISSIONS Best Estimate kg/hr (lb/hr) | High Estimate kg/hr (lb/hr) |
|---|---|---|---|---|---|---|---|---|---|
| St. Joe<br>Monaca, PA | Zone 17<br>Hor 556.1<br>Vert 4502.2 | FBR/AP | 122.0 (400)[7] | 5.5 (18.0)[7] | 336 (145)[7] | 187.0 (396,000)[7] | 7.9 (25.9)[7] | Negligible by Comparison | |
| | | Sinter #1 | 61.0 (200)[7] | 3.4 (11.2)[7] | 325 (126)[7] | 63.2 (134,000)[7] | 7.0 (22.8)[7] | 0.013 (0.029)[8] | 0.013 (0.029)[8] |
| | | Sinter #2 | 31.1 (102)[7] | 1.8 (5.9)[7] | 325 (126)[7] | 4.5 (9,500)[7] | 1.8 (5.8)[7] | 0.001 (0.002)[8] | 0.001 (0.002)[8] |
| | | Sinter #3 | 36.9 (121)[7] | 2.1 (6.9)[7] | 336 (145)[7] | 37.2 (79,000)[7] | 10.7 (35.2)[7] | 0.008 (0.017)[8] | 0.008 (0.017)[8] |
| | | Sinter #4 | 31.7 (104)[7] | 2.0 (6.6)[7] | 325 (126)[7] | 3.5 (7,400)[7] | 1.1 (3.7)[7] | 0.001 (0.002)[8] | 0.001 (0.002)[8] |
| | | Elec. Furn. | 27.4 (89.9)[7] | 8.2 (26.9)[7] | 361 (190)[7] | 161.3 (342,000)[7] | 3.1 (10.0)[7] | Negligible by Comparison | |
| | | Dross Furn. | 12.2 (40.0)[7] | 0.9 (3.0)[7] | 366 (199)[7] | 11.8 (25,000)[7] | 18.5 (60.8)[7] | Negligible by Comparison | |
| ASARCO<br>Corpus Christi, TX | Zone 14<br>Hor 658.0<br>Vert 3075.9 | FBR/AP | 91.5 (300)[14] | 2.0 (6.5)[14] | 389 (240)[17] | 8.5 (18,000)[17] | 2.7 (8.9)[17] | 0.001 (0.0021)[17] | 0.023 (0.050)[13] |
| AMAX<br>Sauget, IL | Zone 15<br>Hor 746.4<br>Vert 4276.2 | FBR/AP | 45.7 (150)[9] | 1.5 (5.0)[9] | 373 (212)[9] | 17.1 (36,000)[9] | 9.7 (31.7)[9] | 0.0028 (0.0062)[13] | 0.045 (0.099)[13] |
| Jersey Miniere Zinc Comp.<br>Clarksville, TN | Zone 16<br>Hor 463.8<br>Vert 4041.0 | FBR/AP | 61.0 (200)[10] | 1.8 (5.9)[10] | 334 (142)[10] | 16.1 (34,000)[10] | 6.3 (20.8)[10] | 0.0030 (0.0065)[13] | 0.047 (0.010)[13] |
| National Zinc<br>Bartelsville, OK | Zone 15<br>Hor 233.7<br>Vert 4070.0 | FBR/AP | 30.5 (100)[11] | 1.3 (4.3)[11] | 325 (126)[11] | 7.5 (16,000)[11] | 5.7 (18.5)[11] | 0.0014 (0.0031)[13] | 0.023 (0.050)[13] |
| ASARCO<br>Columbus, OH | Zone 17<br>Hor 331.0<br>Vert 4429.2 | MHR/AP | 60.7 (199)[12] | 1.2 (3.9)[12] | 333 (140)[12] | 7.5 (16,000)[12] | 6.6 (21.9)[12] | 0.0014 (0.0031)[13] | 0.022 (0.048)[13] |
| New Jersey[a] Zinc<br>Palmerton, PA | Zone 18<br>Hor 450.0<br>Vert 4517.0 | Waelz Kiln | 24.4 (80)[15] | 5.0 (16.4)[16] | 411 (280)[15] | 143 (300,000)[16] | 7.3 (23.9)[16] | 0.58 (1.3)[16] | 0.04 (0.09)[16] |
| | | Sinter | 18.3 (60)[15] | 1.8 (6.0)[15] | 364 (195)[15] | 20.2 (43,000)[16] | 7.9 (25.9)[16] | 0.004 (0.009)[16] | 0.01 (0.02)[16] |
| | | Horiz. Moving Grate Furnace | 22.9 (75)[15] | 2.3 (7.7)[16] | 355 (180)[16] | 31.5 (67,000)[16] | 7.3 (23.9)[16] | 0.01 (0.02)[16] | 0.03 (0.06)[16] |
| | | Fume Kiln | 91.5 (300)[15] | 3.7 (12.0)[16] | 355 (180)[16] | 11.8 (25,000)[16] | 1.1 (3.7)[16] | 0.003 (0.006)[16] | 0.007 (0.02)[16] |

[a] The arsenic emissions estimates shown for the New Jersey zinc plant in the "Best Estimate" and "High Estimate" columns correspond to existing and EBC arsenic emissions, respectively.

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# 6.0 SECONDARY LEAD SMELTING

This chapter discusses the secondary lead industry and its associated arsenic emissions. Section 6.1 presents a brief source category description. Section 6.2 discusses the regulations currently covering the industry and the resulting level of control and associated arsenic emissions. Section 6.3 presents a discussion of the EBC options and Section 6.4 discusses the impacts of applying these options. Section 6.5 presents the input data to be used in assessing the population exposure to arsenic emissions from secondary lead smelting. The ease of standards development is discussed in Section 6.6.

## 6.1 SOURCE DESCRIPTION

### 6.1.1 Industry Description

Lead produced by smelting lead scrap is called secondary lead and accounts for approximately half of the lead produced in the United States. Secondary lead production in 1980 was 676,000 Mg (744,000 tons).[1] The secondary lead industry consists of between 50 to 66[2,3] lead smelters, owned by some 26 companies. The differences in the reported number of smelters may be due to inclusion of some lead refiners who do not reuse lead from scrap but just remelt bullion from blast and reverberatory furnaces and remove some impurities. Secondary lead smelters are located in 26 states and in all ten EPA regions. Table 6-1 lists the major secondary lead smelters in the United States. The 66 plants listed in the table which will be considered in this study are distributed as follows:[2]

1. 18 large plants [with production greater than 22,700 Mg/yr (25,000 tons/yr)];
2. 13 medium plants [with production in the range of 13,000 to 22,700 Mg/yr (15,000 to 25,000 tons/yr)]; and
3. 35 small plants [with production less than 136,000 Mg/yr (15,000 tons/yr)].

### 6.1.2 Process Description

The normal sequence of operations of a secondary lead smelter are scrap receiving, charge preparation, furnace smelting and refining and alloying. As shown in Table 6-2, battery plates constitute the majority of the recycled scrap. In 1980 over 76 percent of the total lead recycled came from this source.

Scrap batteries which contain up to 50 percent by weight of lead have to be broken or sawn open to allow removal of the lead plates and lead

TABLE 6-1. MAJOR SECONDARY LEAD SMELTERS IN THE UNITED STATES[a]

| Plant Location | Annual Capacity $10^3$ Mg | Furnaces | | |
|---|---|---|---|---|
| | | Blast | Reverberatory | Rotary |
| Interstate Lead Co., Inc.<br>Leeds, AL | 30 | 1 | 1 | |
| Sanders Lead Company<br>Troy, AL | 50 | 2 | 2 | |
| RSR Corporation<br>City of Industry, CA | 30 | | 1 | |
| ALCO Mining, Inc.<br>Gardena, CA | 5 | | | 1 |
| South West Metal<br>San Bernardino, CA | 15 | | | 1 |
| ASARCO<br>San Francisco, CA | N/A | | 1 | |
| Gould, Inc.<br>Vernon, CA | 36 | 2 | 2 | |
| National Smelting & Refining<br>Denver, CO | N/A | | | |
| Refined Metals Corp.<br>Jacksonville, FL | 12 | 1 | 1 | |
| Globe Union, Inc.<br>Tampa, FL | N/A | | | |
| Gulf Coast Lead Co.<br>Tampa, FL | 15 | 1 | | |
| NL Industries, Inc.<br>Atlanta, GA | 18 | 1 | | |
| TARACORP<br>Atlanta, GA | 30 | 1 | 1 | |
| Sanders Lead Co.<br>Cedartown, GA | 50 | 2 | 2 | |

TABLE 6-1. (Continued) MAJOR SECONDARY LEAD SMELTERS IN THE UNITED STATES[a]

| Plant Location | Annual Capacity $10^3$ Mg | Furnaces | | |
|---|---|---|---|---|
| | | Blast | Reverberatory | Rotary |
| Chloride Metals<br>Columbus, GA | 12 | 1 | | |
| TARACORP<br>Granite City, IL | 24 | 1 | | |
| TARACORP<br>McCook, IL | 12 | | 1 | |
| North Chicago Smelting & Refining<br>North Cook, IL | N/A | | | |
| Refined Metals Corp.<br>Beach Grove, IN | 20 | 1 | | |
| USS Lead Refining, Inc.<br>E. Chicago, IN | 20 | 1 | | |
| Northern Indiana Dock Co.<br>E. Chicago, IN | N/A | | 1 | |
| RSR-Quemetco Corp.<br>Indianapolis, IN | 20 | 1 | | |
| Mincon (Sold to Bergsoe)<br>Muncie, IN | 22 | 1 | 1 | |
| ASARCO<br>Whiting, IN | N/A | 1 | 1 | |
| Delco Remy Battery<br>Olathe, KS | N/A | | 1 | |
| Schuykill Metals Corp.<br>Baton Rouge, LA | 60 | 2 | 2 | |
| General Battery Corp.<br>Heflin, LA | 13 | | 1 | |
| Sommerville Smelting<br>Sommerville, MA | N/A | | 3 | |

TABLE 6-1. (Continued) MAJOR SECONDARY LEAD SMELTERS IN THE UNITED STATES[a]

| Plant Location | Annual Capacity $10^3$ Mg | Furnaces<br>Blast | <br>Reverberatory | <br>Rotary |
|---|---|---|---|---|
| New England Smelting Works<br>W. Springfield, MA | N/A | | | |
| Federal Alloys<br>Detroit, MI | Shutdown | | | |
| Industrial Smelting Co.<br>Detroit, MI | N/A | | | |
| TARACORP Industries<br>St. Louis Park, MN | 12 | | 1 | |
| Gopher Smelting & Refining Co.<br>St. Paul, MN | 18 | 1 | 1 | |
| Chloride Metals, Inc.<br>Florence, MS | 12 | 1 | | |
| Schuykill Metals<br>Forest City, MO | 30 | 1 | | |
| Gould, Inc.<br>Omaha, NE | 12.5 | 1 | | |
| Delco Remy Battery<br>New Brunswick, NJ | N/A | | 2 | |
| Essex Metal Alloys<br>Newark, NJ | N/A | | | |
| Aetna Alloys Division<br>Newark, NJ | N/A | | | |
| NL Industries<br>Pedricktown, NJ | 70 | | | 1 |
| E. L. Beth<br>Perth Amboy, NJ | N/A | | | 1[c] |
| CAL-WEST<br>Socorro, NM | N/A | | | |

TABLE 6-1. (Continued) MAJOR SECONDARY LEAD SMELTERS IN THE UNITED STATES[a]

| Plant Location | Annual Capacity $10^3$ Mg | Furnaces | | |
|---|---|---|---|---|
| | | Blast | Reverberatory | Rotary |
| Republic Metals<br>Brooklyn, NY | N/A | | 1 | |
| Roth Bros. Smelting Corp.<br>Dewitt, NY | N/A | | 1 | |
| Willard Lead Co.<br>Charlotte, NC | 10 | 1 | | |
| Master Metals, Inc.<br>Cleveland, OH | 24 | 1 | | |
| River Smelting & Refining<br>Cleveland, OH | N/A | | | |
| Bergsoe Metal Corporation<br>Portland, OR | 27 | | b | |
| Lancaster Battery Co.<br>Lancaster, PA | N/A | 1 | | |
| East Penn Manufacturing Co.<br>Lyons Station, PA | 15 | 1 | | |
| Tonolli Corp.<br>Nesquehoning, PA | 40 | | | 4 |
| Gould, Inc.<br>Philadelphia, PA | N/A | | 1 | |
| Imperial Metal Co.<br>Philadelphia, PA | N/A | | 1 | |
| General Battery Corp.<br>Reading, PA | 60 | 2 | 2 | |
| Marjol Battery Corp.<br>Throop, PA | N/A | | | |
| General Smelting & Refining<br>College Grove, TN | N/A | 1 | | |

TABLE 6-1. (Continued) MAJOR SECONDARY LEAD SMELTERS IN THE UNITED STATES[a]

| Plant Location | Annual Capacity $10^3$ Mg | Furnaces |  |  |
|---|---|---|---|---|
|  |  | Blast | Reverberatory | Rotary |
| Refined Metals Corp.<br>Memphis, TN | 24 | 1 | 1 |  |
| Ross Metals, Inc.<br>Rossville, TN | 9 | 1 | 1 |  |
| General Battery Corp.<br>Dallas, TX | 25 | 1 | 1 |  |
| RSR Corporation<br>Dallas, TX | 60 | 1 | 2 |  |
| NL Industries, Inc.<br>Dallas, TX | Shutdown | 1 |  |  |
| Gould, Inc.<br>Frisco, TX | 30 | 1 | 2 |  |
| Houston Lead Co.<br>Houston, TX | Shutdown |  | 1 |  |
| Standard Industries<br>San Antonio, TX | N/A |  |  |  |
| Hyman Viener & Sons<br>Richmond, VA | N/A | 1 | 1 |  |
| RSR Corporation<br>Seattle, WA | 20 |  | 1 |  |
| Crown Metal<br>Milwaukee, WI | N/A |  |  |  |

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[a] Information compiled from the Lead Industries Association, a NEDS listing, State air pollution control agency contacts.

[b] Bergsoe type furnace.

[c] Furnace is either under construction or not operating.

NA = Data not available, most likely to be less than 15,000 tons/year production or refiners using pot furnaces.

TABLE 6-2. CONSUMPTION OF NEW AND OLD LEAD SCRAP BY SMELTERS AND REFINERS IN THE UNITED STATES IN 1980 (Metric tons, gross weight)

| Class of Consumer and Type of Scrap | Stocks Jan. 1 | Receipts | Consumption | | | |
|---|---|---|---|---|---|---|
| | | | New Scrap | Old Scrap | Total | % |
| Smelters and refiners: | | | | | | |
| Soft lead . . . . . . . . . . . . . | 1,334 | 31,819 | -- | 31,165 | 31,165 | 3.3 |
| Hard lead . . . . . . . . . . . . . | 1,334 | 18,290 | -- | 17,940 | 17,940 | 1.9 |
| Cable lead . . . . . . . . . . . . | 4,800 | 11,469 | -- | 11,565 | 11,565 | 1.2 |
| Battery-lead plates . . . . . . . . | 42,381 | 719,438 | -- | 727,095 | 727,095 | 76.3 |
| Mixed common babbitt . . . . . . | 254 | 6,851 | -- | 6,938 | 6,938 | .7 |
| Solder and tinny lead . . . . . . | 1,315 | 11,564 | -- | 10,948 | 10,948 | 1.1 |
| Type metals . . . . . . . . . . . . | 2,528 | 13,793 | -- | 14,413 | 14,413 | 1.5 |
| Drosses and residues . . . . . . . . | 20,145 | 125,525 | 133,186 | -- | 133,186 | 14.0 |
| Total . . . . . . . . . . . . . | 74,091 | 938,749 | 133,186 | 820,064 | 953,250 | 100 |

Source: Bureau of mines

oxide. This operation can be done manually or mechanically. Some secondary lead smelters crush and grind whole batteries and then separate the component parts using heavy media float-sink separators.[4]

Prepared battery scrap is then combined with other furnace feed materials and charged to the furnace. There are three types of smelting furnaces commonly used at secondary lead smelters. These are blast, reverberatory, and rotary (i.e., rotary reverberatory) furnaces. Table 6-3 compares the three types of furnaces. The following paragraphs will discuss each furnace type in further detail.

A simplified flow diagram of a single blast furnace system is presented in Figure 6-1.[5] A blast furnace is a vertical unit and is charged through a door at or near the top of the furnace. The blast furnace charge material typically consists of: 82.5 percent reverberatory slag which consists of oxidized lead and other metal oxides and reduction drosses from the refining operation; 5.5 percent coke (for combustion); 3 percent limestone; 4.5 percent scrap iron; and 4.5 percent rerun slag (from previous runs).[6] Air is "blasted" [using 24-32 Pa (8-12 oz/in$^2$) gauge pressure] into the furnace through tuyeres near the base. Oxygen enrichment is sometimes used to increase metal production and recovery of antimony and arsenic values.[7] Oxygen enrichment also lowers fume production and coke usage.

As the charge material melts, the iron, silica and limestone form an oxidant-retardant flux which floats to the top of the melt. Molten lead is tapped almost continuously into a holding pot. When battery groups are being charged approximately 70 percent of the charge material is tapped off as hard (or antimonial) lead, which may contain as much as 12 percent antimony. The molten lead is cast into large ingots called "buttons" or "sows." Approximately 7 percent of the charge leaves the furnace as dust and 18 percent of the remaining material is tapped as slag and matte. Approximately 5 percent of the slag is recharged into the blast furnace. A typical range for blast furnace production is 18 to 73 Mg/day (20-80 tons/day).

There is a wide range of temperatures found throughout the charge column in a blast furnace. Temperatures of 1230°C (2240°F) or greater are encountered in the slag zone and adjacent to the tuyeres. Lower temperatures are encountered up the charge column and typical gas exit temperatures at the top of the blast furnace are 430-540°C (800-1000°F).

The major sources of air pollutant emissions from a blast furnace are shown in Figure 6-1. Typically, furnace emissions are controlled by an afterburner, a baghouse, and/or a scrubber. Knock-out boxes are frequently used for collection of particulate which separates from the gas flow in the ducts. Furnace emissions are discharged to the atmosphere through a stack. Charging, slag tapping, and lead tapping are process fugitive emission sources and may be hooded and ducted to the process baghouse or to a separate sanitary baghouse for recovery of lead-containing particulate.

## TABLE 6-3. COMPARISON OF FURNACE CHARACTERISTICS

| | TYPE OF FURNACE | | |
|---|---|---|---|
| CHARACTERISTIC[b] | BLAST | REVERBERATORY | ROTARY[a] |
| Charge material[b] | Reverberatory slag<br>Drosses<br>Lead scrap<br>Antimonial ore<br>Iron scrap<br>Sand<br>Limestone<br>Recycled blast furnace slag<br>Reducing agents: Coke, sawdust, ground battery cases | Crushed batteries or battery plates<br>Lead scrap<br>Flue dust<br>Carbon | Batteries<br>Lead paste<br>Cast iron borings<br>Anthracite<br>Limestone<br>Soda ash[c] |
| Fuel | Coke | Natural gas; No. 2 fuel oil | Natural gas; No. 2 fuel oil |
| Operation | Batch/semi-continuous | Continuous | Batch |
| Products | Hard lead | Semisoft lead | Semisoft lead; lead oxide |
| Typical air pollution device | Afterburner<br>Cooling device<br>Baghouse | Cooling device<br>Baghouse | Cooling device<br>Baghouse |
| Operating temperature °C (°F) | 430-1320 (800-2400[d]) | 1260-1320 (2300-2400) | 1260-1320 (2300-2400) |
| Exit temperature of furnace offgas °C (°F) | 430-730 (800-1350) | 1260-1320 (2300-2400) | 1260 (2300) |
| Nominal furnace capacity Mg/day (tons/day) | 36 (40) | 45 (50) | 36 (40) |

---

[a] Short rotary furnace only; does not include a long rotary kiln.

[b] For typical furnace operations. Significant variations can occur from plant to plant.

[c] For soda matte process; removal of SO as slag.

[d] Temperature varies throughout blast furnace column. Highest temperatures will occur around or just above the blast zone.

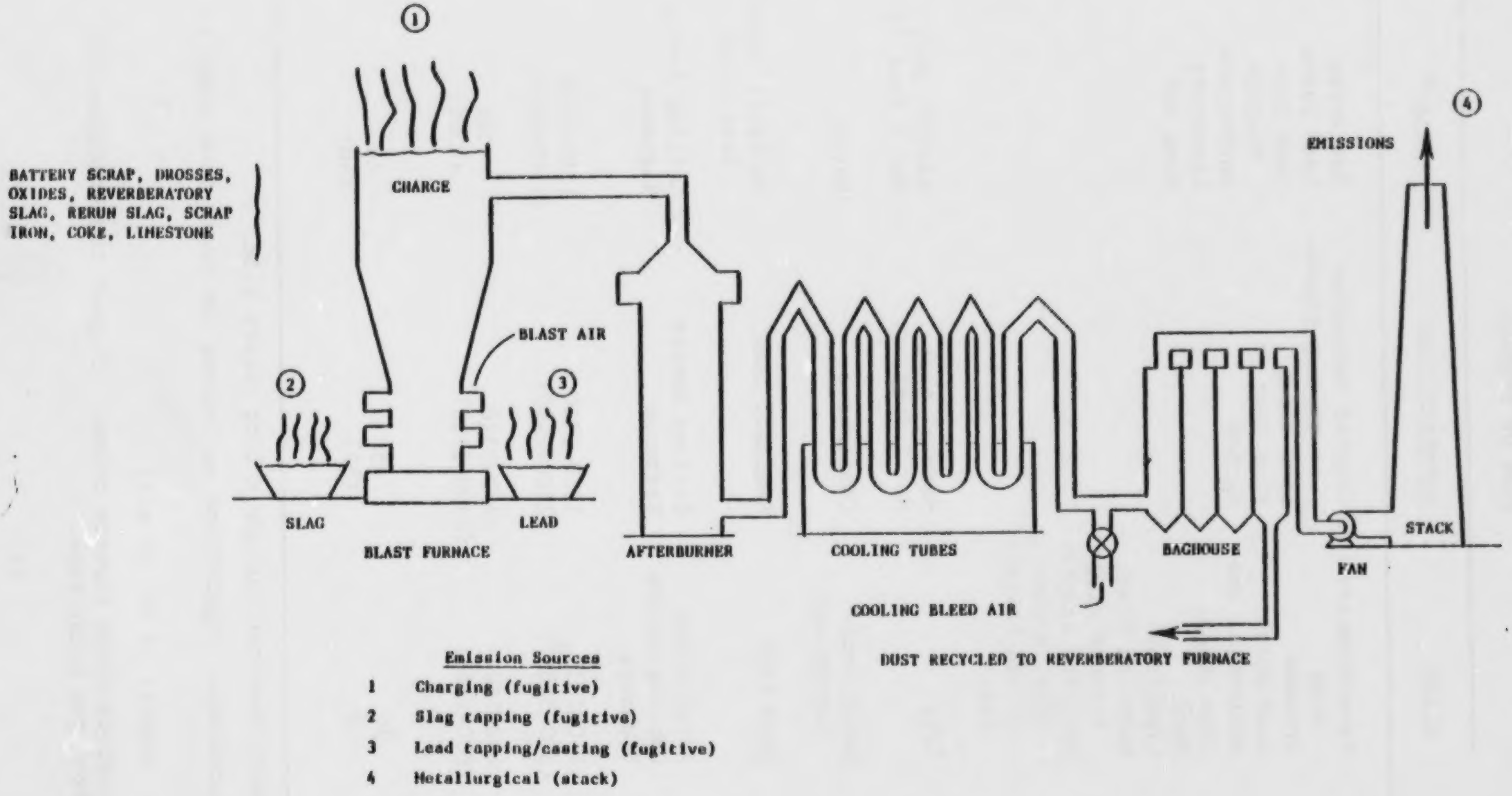
①
④
EMISSIONS
BATTERY SCRAP, DROSSES, OXIDES, REVERBERATORY SLAG, RERUN SLAG, SCRAP IRON, COKE, LIMESTONE
CHARGE
BLAST AIR
②
③
SLAG
LEAD
BLAST FURNACE
AFTERBURNER
COOLING TUBES
BAGHOUSE
FAN
STACK
COOLING BLEED AIR
DUST RECYCLED TO REVERBERATORY FURNACE
Emission Sources
1 Charging (fugitive)
2 Slag tapping (fugitive)
3 Lead tapping/casting (fugitive)
4 Metallurgical (stack)

Figure 6-1. Typical blast furnace system for secondary lead production.[7]

A simplified flow diagram of a single reverberatory furnace system is presented in Figure 6-2.[5] The reverberatory furnace uses gas- or oil-fired burners. The charge material is heated by radiation from the flame and from the furnace walls. As indicated in Figure 6-2, the reverberatory furnace charge material typically includes: lead scrap, battery plates, lead oxides and recycled flue dusts. Charge material is added as more of the solid material in the furnace becomes liquid. The reverberatory furnace operates at a temperature of about 1260°C (2300°F) and near atmospheric pressure. Molten metal (i.e., semisoft lead containing 0.3 to 0.4 percent antimony) is tapped into molds periodically as the level rises in the furnace. Typically, a reverberatory furnace produces 45 Mg/day (50 tons/day). Approximately 47 percent of input is recovered as lead, 46 percent is slag, and 7 percent is lost as particulate and metal fume.

The rotary furnace, which is similar to the reverberatory furnace, is used in Europe in most secondary lead plants. A major difference between the rotary and reverberatory furnaces is that the rotary furnace rotates slowly during heating of the charge material.

A reverberatory (or rotary) furnace can be used simultaneously to: (a) reclaim lead from oxides and drosses, or (b) sweat lead from metallic scrap. Sweating utilizes the differences in melting points to separate lead from other metals.

Figure 6-2 indicates the major sources of air pollutant emissions from a reverberatory furnace. Furnace (nonfugitive) emissions are typically controlled by an exhaust gas settling chamber, a baghouse, and/or a scrubber. Process fugitive emissions from charging, lead tapping, and slag tapping may be hooded and ducted to a separate baghouse.

Following the smelting operation the hard and semisoft lead is further refined and alloyed as necessary. Refining and alloying are done in pot furnaces. The process is a batch operation and may take a few hours to 2-3 days depending upon the degree of purity or alloy type required. Pot furnaces are gas- or oil-fired and range in capacity from 1 to 45 Mg (1-50 tons). Pot furnaces operate at temperatures ranging from 320°C to 480°C (600°F to 900°F) and in addition are usually hooded. Emissions from pot furnaces are therefore lower than from blast and reverberatory furnaces.

### 6.1.3 Arsenic Emissions from Secondary Lead Smelters

Emissions from secondary lead smelters occur from three groups of sources. These are the process sources, the process fugitive sources and the nonprocess or area fugitive sources. The predominant sources of process emissions are the smelting furnaces and the refining pots. Process fugitive emissions are generated during charge preparation, furnace operations and refining operations. There are also several nonprocess fugitive emission sources throughout the plant including the raw material storage piles, the

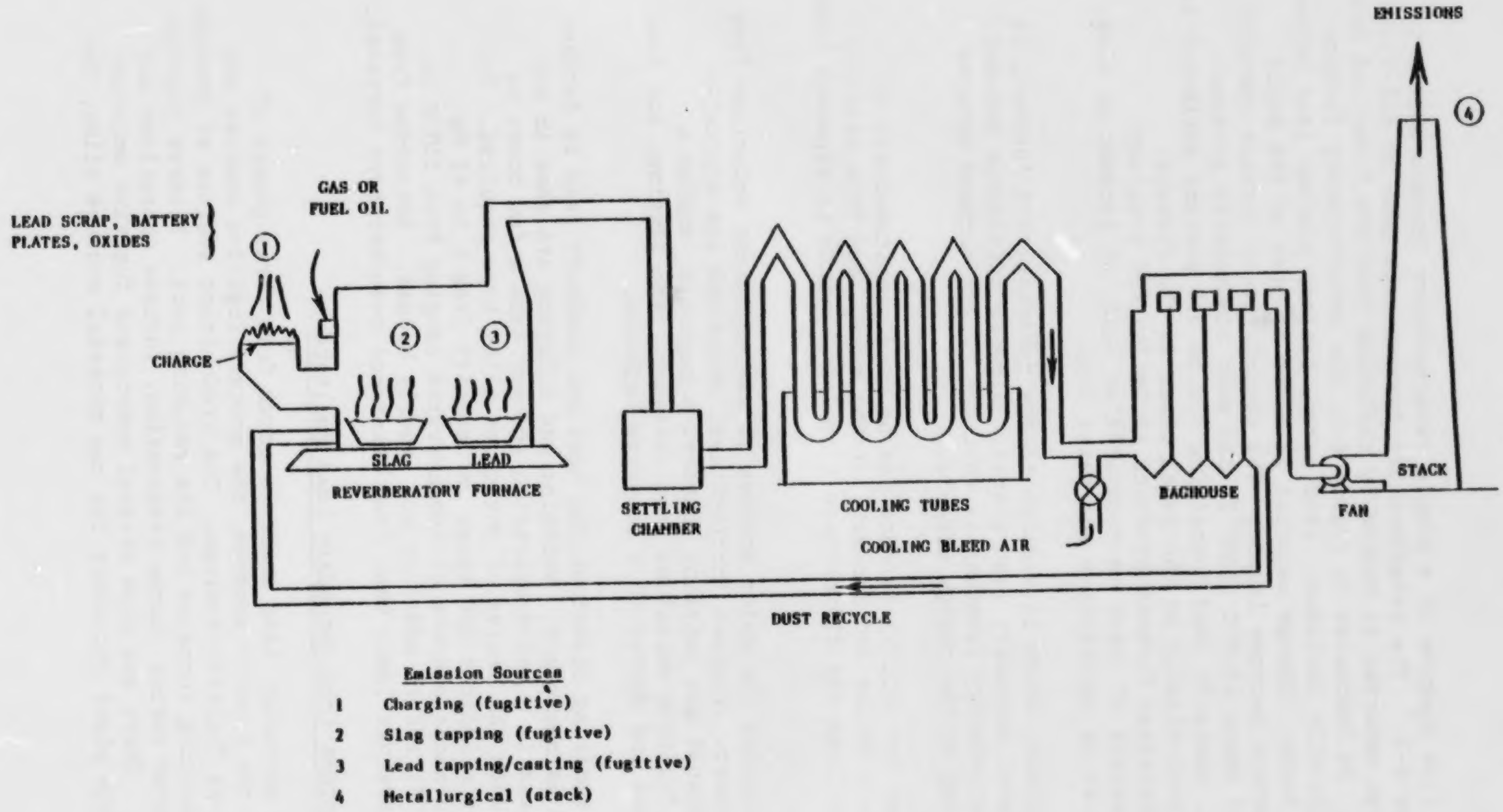
EMISSIONS
④
LEAD SCRAP, BATTERY PLATES, OXIDES
GAS OR FUEL OIL
①
CHARGE
②
③
SLAG
LEAD
REVERBERATORY FURNACE
SETTLING CHAMBER
COOLING TUBES
COOLING BLEED AIR
BAGHOUSE
FAN
STACK
DUST RECYCLE
Emission Sources
1 Charging (fugitive)
2 Slag tapping (fugitive)
3 Lead tapping/casting (fugitive)
4 Metallurgical (stack)

Figure 6-2. Typical reverberatory furnace system for secondary lead production.[7]

haul roads, and the charge preparation area. Fugitive emission sources common to most secondary lead smelters are listed in Table 6-4.[8]

Arsenic is present in many of the furnace feed materials and in all of the furnace products. Figure 6-3 illustrates the many input and outputs from typical blast and reverberatory furnaces. Table 6-5 gives ranges or typical amounts for each feed material and the range of observed arsenic contents. A detailed arsenic material balance cannot be constructed using the data presented in Table 6-5 because of the wide ranges reported in both weights of feed materials and arsenic contents.

During the smelting operations the arsenic containing raw materials are subjected to high furnace temperatures and either oxidizing or reducing conditions. In the reverberatory furnace, which produces an oxidizing environment for most lead alloying constituents, some arsenic trioxide is formed. This can vaporize and leave the furnace in the offgases. Alternatively the arsenic can become complexed in the slag and leave the furnace in this stream. Most reverberatory slags which are predominantly composed of metal oxides are charged to blast furnaces to recover the lead values. The blast furnace has a lower exhaust gas exit temperature than the reverberatory furnace and in addition operates under a reducing environment. Any arsenic in the charge materials either vaporizes and exits the furnace in the blast furnace offgases or dissolves in the product metal. Very little arsenic remains in the blast furnace slag.[4,7]

Many factors can affect the emissions from the smelting operations, including the amount of arsenic in the feed material, the operating conditions of the furnace, the amount of chlorides in the feed material, and the slag composition. Table 6-5 shows that the amount of arsenic present in a given feed material can vary widely. In addition, the type of material charged to any furnace varies widely from smelter to smelter. For example, some plants charge whole batteries and others charge carefully segregated plates and scrap. Arsenic emissions in terms of g/kg of lead produced could therefore vary widely from plant to plant.

Furnace operating conditions can vary widely from smelter to smelter. Reverberatory furnaces can be operated to conserve arsenic and antimony values in the slag. Similarly blast furnaces can be operated to conserve these metal values in the product metal, or can be operated to produce a metal with lower arsenic and antimony contents. The amount of chlorides in the furnace charge material could also affect the amount of arsenic emissions. If any chlorides are present in the feed material, arsenic trichloride, a very volatile compound may be formed and subsequently liberated from the furnace. Secondary lead smelters who charge whole batteries and groups of battery plates which contain polyvinylchloride plate separators would be expected to have higher arsenic emissions than smelters who charge only battery plates and battery mud.

## TABLE 6-4. FUGITIVE EMISSION SOURCES AND CONTROL METHODS

| Fugitive Emission Source | Control Methods[a] |
|---|---|
| I. PROCESS FUGITIVE EMISSIONS | |
| A. Battery breaking | Hoods and scrubber/FF |
| Battery/charge preparation | Washing down by hose |
| B. Furnace operations | Hoods ducted to a separate baghouse |
| 1. Charging | |
| 2. Slag tapping | Slag caster |
| 3. Lead tapping | |
| C. Refining | Hoods ducted to a separate control device |
| D. Casting | Hoods |
| II. NONPROCESS FUGITIVE EMISSIONS | |
| A. Raw materials | Enclosure; separation; covering with plastic sheets; wetting down by hose |
| 1. Unloading of trucks/railcars | |
| 2. Storage/wind erosion | |
| 3. Transfer to furnace area | |
| B. Product/scrap materials | Agglomeration of flue dust, enclosure, separation, wetting down by hose; washing of trucks before leaving plant property |
| 1. Transfer to storage | |
| 2. Storage | |
| 3. Loading to trucks/railcars | |
| C. Furnace area floors | Paving, vacuuming, wetting down by hose |
| D. Alloying department floors | Oiled sawdust on floor — vacuumed and charged to blast furnace |
| E. Paved/unpaved roads | Paving, vacuuming, wetting down by hose |
| 1. Vehicular activity | |
| 2. Storage | |
| 3. Loading to trucks/railcars | |

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[a] Observed in varying degrees at some or all of the nine plants visited in the MRI study. (Reference 2)

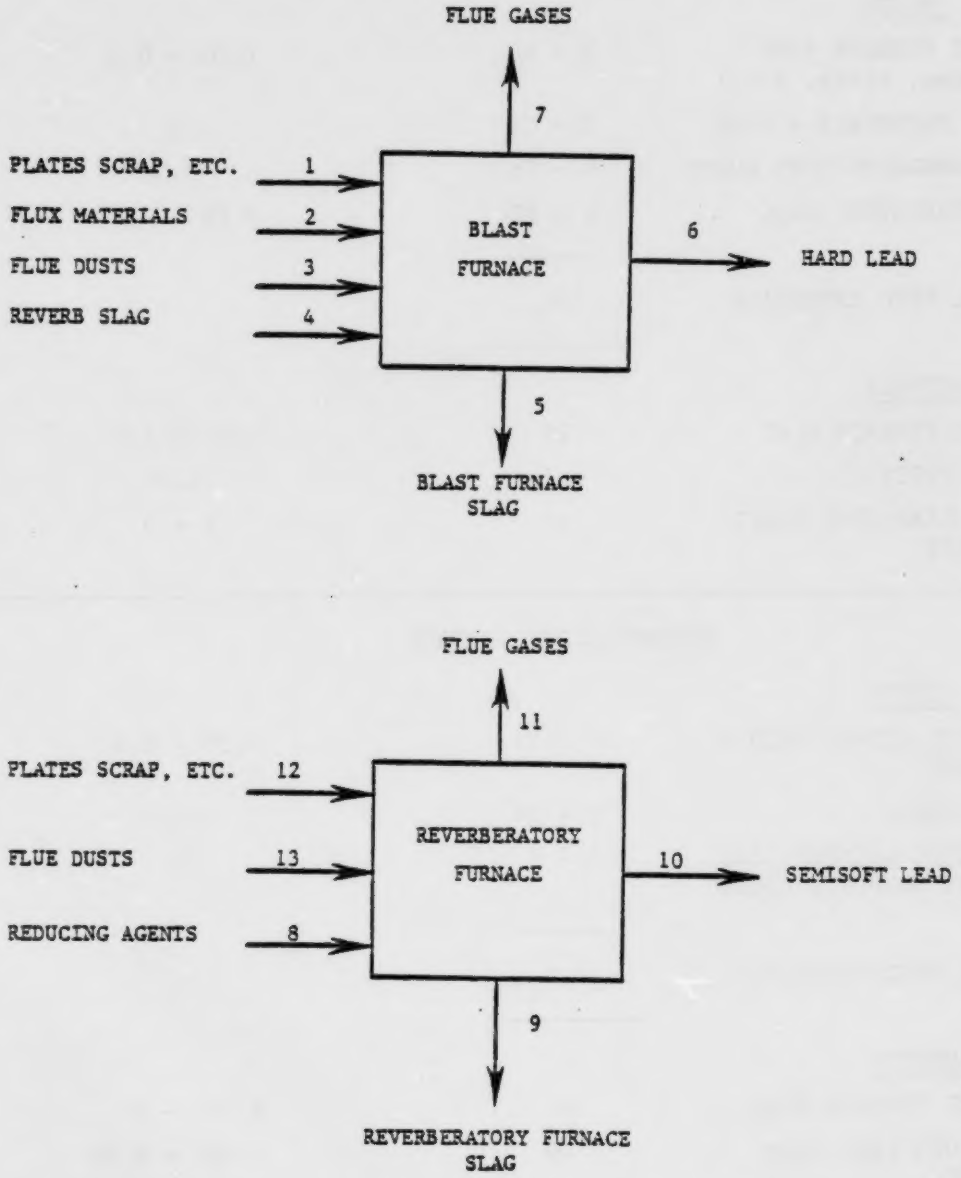
FLUE GASES
7
PLATES SCRAP, ETC.
1
FLUX MATERIALS
2
FLUE DUSTS
3
REVERB SLAG
4
BLAST FURNACE
6
HARD LEAD
5
BLAST FURNACE SLAG
FLUE GASES
11
PLATES SCRAP, ETC.
12
FLUE DUSTS
13
REDUCING AGENTS
8
REVERBERATORY FURNACE
10
SEMISOFT LEAD
9
REVERBERATORY FURNACE SLAG

Figure 6-3. Secondary lead material balance.

TABLE 6-5. SECONDARY LEAD MATERIAL BALANCE
(Typical Reported Values)[4,7,27]

| STREAM (From Fig. 6-3) | WEIGHT % of FEED | ARSENIC CONTENT Wt % |
|---|---|---|
| | BLAST FURNACE | |
| INPUTS | | |
| 1. BLAST FURNACE FEED (Plates, Scrap, etc.) | 0 - 80 | 0.05 - 0.2 |
| 2. FLUX MATERIALS & COKE | 5 - 20 | 0 |
| 3. AGGLOMERATED FLUE DUSTS | 0 - 15 | 0.3 |
| 4. REVERBERATORY SLAG | 0 - 80 | 0.003 - 2 |
| TOTAL FEED MATERIALS | 100 | |
| OUTPUTS | | |
| 5. BLAST FURNACE SLAG | 28 | 0.001 - 1.0 |
| 7. FLUE DUSTS | 7 | 0.3 |
| 6. HARD LEAD FROM BLAST FURNACE | 65 | 1 - 3 |
| | REVERBERATORY FURNACE | |
| INPUTS | | |
| 12. BATTERY SCRAP, OXIDES DROSSES | 70 - 95 | 0.05 - 0.2 |
| 13. FINE DUSTS | 0 - 10 | 0.3 |
| 8. REDUCING AGENTS (COAL FINES, SAWDUST, ETC.) | 0 - 5 | 0 |
| TOTAL FEED MATERIALS | 100 | |
| OUTPUTS | | |
| 9. REVERB FURNACE SLAG | 47 | 0.003 - 2 |
| 10. SEMISOFT LEAD FROM REVERB | 46 | 0.001 - 0.05 |
| 11. FLUE DUSTS | 7 | 0.3 |

Blast furnace slag composition can have an affect on arsenic emissions. Arsenic forms complexes with iron and other metals and can be removed from the furnace as part of the slag, thereby reducing arsenic levels in blast furnace offgases.

There are three main sources of process fugitive arsenic emissions. These are the charging operation, the slag tapping operation and the metal pouring operation.

The magnitude of arsenic emissions from process fugitive sources would be expected to vary with the arsenic content of the charge material. Emissions from the charging operation will consist of fine particulates and fumes. When the blast furnace is charged some of the furnace offgases will exit the furnace through the charge hole. If the charge contains any fine material this can be entrained and become a potential process fugitive emission. The major source of fines in secondary lead smelter charge material is the recycled flue dusts. As shown earlier these dusts contain an appreciable amount of arsenic. Several smelters are currently using an agglomeration furnace to process flue dusts prior to recycling them to the process. The agglomeration step produces a material which is more easily handled and less subject to dusting.

During the slag and metal tapping operations a considerable amount of fumes are generated because of the high temperatures involved. If these fumes are not captured and controlled they can constitute process fugitive emissions. Most furnace tapping operations are currently equipped with capture hoods and fabric filters. The arsenic content of the fumes generated during slag tapping and metal pouring should reflect the pouring temperature and the arsenic content of the slag and product metal respectively. The arsenic contents of the slag and product metal in turn should reflect the amount of arsenic in the charge material and the effects of the furnace operating procedures.

Arsenic emissions from area sources will be influenced by the arsenic content of the various fine materials being stored around the smelter. This includes the non-agglomerated flue dusts and the dried battery mud. Other factors which will influence the total amount of arsenic for this source include the meterological conditions, especially the amount of wind and rain, and the amount of activity around the plant site.

## 6.2 INORGANIC ARSENIC EMISSIONS UNDER EXISTING REGULATIONS

### 6.2.1 Regulatory Impacts

All of the point sources in an existing secondary lead smelter are covered by the applicable SIP process weight regulation for particulate and in some cases the NSPS for particulate emissions from secondary lead smelters. The NSPS which requires particulate emissions from reverberatory and blast furnaces to be less than 50 mg/m$^3$ (0.022 gr/dscf) is the more stringent of the two regulations. Available data indicates that the majority of secondary lead smelters are easily complying with the applicable SIP and NSPS. In most cases the smelters are exceeding the NSPS requirments. In addition to particulate regulations, some States and local agencies are requiring control of $SO_2$ emissions from reverberatory and blast furnaces.

Fugitive particulate emission sources are currently impacted by three regulations. These are (1) the OSHA workplace standard for lead, (2) the EPA national ambient air quality standard (NAAQS) for particulate and, (3) the EPA NAAQS for lead. These three regulations are briefly discussed below.

The Occupational Safety and Health Administration (OSHA) standard, recently proposed, limits in-plant lead concentrations to 50 $\mu g/m^3$ based on 8-hour worker exposure. This standard directly affects the control of process and some nonprocess emission sources within a secondary lead plant. Individual plants are being evaluated to determine work practices, control equipment, and ventilation measures that will be needed to achieve the OSHA standard. All of the existing fugitive emission control technology now used in the secondary lead industry was instituted to meet the OSHA standard.

The EPA National Ambient Air Quality Standard (NAAQS) for particulate limits ambient concentration to 260 $\mu g/m^3$ (primary standard) and 150 $\mu g/m^3$ (secondary secondard) for a 24-hour period. No evidence was found that the standard was violated at or around any of the secondary lead plants visited by MRI, as part of the NSPS revision project for secondary lead smelters.[9]

The EPA NAAQS for lead limits the ambient concentration to 1.5 $\mu g/m^3$ for a 3-month average. The standard, promulgated in 1978, requires the States to revise State implementation plans (SIP) to pinpoint areas where emission control is needed. Personnel at several plants visited by MRI indicated that this standard was not being met at or around their plant.[9]

### 6.2.2 Existing Controls and Inorganic Arsenic Emissions

6.2.2.1 Process Sources. As a result of complying with the applicable SIPs and NSPS most secondary lead smelters have applied fabric filters to control particulate emissions from their blast and reverberatory furnaces. Typically these fabric filters are preceded by an afterburner and cooler when used on a blast furnace and a cooler alone when used on a reverberatory furnace. Several secondary lead smelters have also installed a scrubber after the fabric filter to control $SO_2$ emissions. There are very little arsenic emissions data available for secondary lead smelters. An uncontrolled emission factor of 0.4 kg/Mg lead produced has been used in several studies of the secondary lead industry, however the basis of this emissions factor appears to be engineering judgement combined with analogy to primary lead smelters.[10,11]

The California Air Resources Board has conducted an arsenic emissions test on the outlet of a fabric filter controlling a reverberatory furnace and a blast furnace. Results of this test are not available at this time.[12]

As discussed earlier, no precise material balance can be constructed around a typical smelter or furnace because of the wide ranges in arsenic contents of the feed materials and variability in operating practices.

However, particulate and lead emissions from furnaces at secondary lead smelters have been well characterized, Table 6-6 presents some test results for fabric filters and scrubbers applied to blast and reverberatory furnaces. In general blast furnaces have slightly higher particulate and lead emissions rates than reverberatory furnaces. For the tests listed in Table 6-6 blast furnaces emitted 14 percent more particulates than a reverberatory furnace on a g/kg lead produced basis.

Several studies have shown that lead and arsenic behave in a similar manner when exposed to high temperature environments. These studies, which are discussed below, will be used as the basis for drawing parallels between lead and arsenic emissions from secondary lead smelters. In addition, the studies are supportive of using control device efficiency measurements based on lead to estimate arsenic removal efficiencies.

Two studies of the behavior of trace elements during coal combustion have shown that lead and arsenic behave in a similar manner. Both are preferentially enriched in the fly ash relative to the bottom ash and both show increasing enrichment with decreasing fly ash particle size.[17,18] This behavior has been attributed to a volatilization/condensation mechanism occurring during the passage of the flue gas through the coal-fired boiler. The elements and their compounds are volatilized in the high temperature combustion zone and then either condense or adsorb onto entrained particles as the flue gases cool down as they pass through the boiler and control devices. The mass deposited is greater per unit weight for the smallest particles since these have the highest surface area. Table 6-7 shows the enrichment ratios reported for lead and arsenic from several studies. The table shows that lead and arsenic track each other fairly well.

The combustion zone of a coal-fired power plant is considerably hotter than a reverberatory or blast furnace. In addition, the initial concentrations of lead and arsenic in coal are considerably lower and at different ratios than that found in secondary lead furnace charge materials. However, secondary lead smelters operate at above 1000°C (1830°F) which is sufficient to vaporize considerable quantities of both elements and their oxides and chlorides. Figure 6-4 shows the vapor pressures of several species which are present in both blast and reverberatory furnaces. Several lead compounds and all arsenic compounds exhibit appreciable vapor pressures above 1000°C (1830°F).

## TABLE 6-6. EMISSIONS TEST RESULTS FOR SECONDARY LEAD SMELTERS

| PLANT | SOURCE | CONTROL DEVICE | TEMPERATURE °C (°F) | PARTICULATE μg/Nm$^3$ (gr/dscf) | LEAD μg/Nm$^3$ (gr/dscf) | FLOW m$^3$/Mg Pb (dscf/ton Pb) |
|---|---|---|---|---|---|---|
| Sanders[13] Lead | Blast Furnace | AB[a]/Fabric Filter | - | 0.5 (0.0002) | - | |
| Tonolli[14] | Rotary Furnace | AB/Fabric Filter | 31 (87) | 14 (0.00616) | 0.3 (0.00013) | |
| (Fabric Filter & Scrubber in Series) | | Scrubber | - | 28.7 (0.01264) | 0.5 (0.00024) | |
| | | AB/Fabric Filter/ Scrubber | - | 54.5 (0.024)<br>45.5 (0.020) | 0.4 (0.00018)<br>0.2 (0.00007) | |
| General[15] Battery | | AB/Fabric Filter/ Scrubber | 36 (96) | 22.7 (0.01) | 0.3 - 0.6 (0.00014 - 0.00025) | |
| A[16] | Blast Furnace | AB/Fabric Filter | 82 (178) | 5.9 (0.0026) | 0.8 (0.00034) | 14,853 (462,700) |
| B | Blast Furnace | AB/Fabric Filter/ Scrubber | 49 (121) | 18 (0.0079) | 0.3 (0.00012) | 15,736 (490,200) |
| C | Blast Furnace | Scrubber | 35 (95) | 32.5 (0.0143) | 2.4 (0.00105) | 15,810 (592,500) |
| D | Blast Furnace | AB/Fabric Filter | 67 (152) | 3.0 (0.0013) | 1.4 (0.00061) | 10,320 (321,500) |
| E | Blast Furnace | AB/Fabric Filter | 79 (175) | 13.4 (0.0059) | - | 31,300 (975,000) |
| F | Blast Furnace | AB/Fabric Filter | 43 (110) | 32.3 (0.0142) | - | 6,565 (204,500) |
| G | Reverb Furnace | Fabric Filter | 76 (168) | 8.0 (0.0035) | 1.4 (0.00061) | 3,450 (419,000) |
| H | Reverb Furnace | Fabric Filter | 51 (124) | 7.5 (0.0033) | 0.9 (0.00038) | 17,662 (550,200) |
| I | Reverb Furnace | Fabric Filter | 164 (327) | 5 (0.0022) | - | 23,565 (734,100) |
| AVERAGE FABRIC FILTER | | | 80 (176) | 9.8 (0.0043) | 0.9 (0.000414) | |
| AVERAGE FABRIC FILTER/ SCRUBBER COMBINATION | | | 38 (101) | 22.7 (0.010) | 0.4 (0.00017) | |

[a] AB = afterburner

## TABLE 6-7. ENRICHMENT RATIOS AND CONTROL DEVICE PERFORMANCE FOR ARSENIC AND LEAD EMISSIONS FROM COAL-FIRED POWER PLANTS

ENRICHMENT RATIOS[17]

| Element | Fly ash |  |  |  | Ratios |  |  |
|---|---|---|---|---|---|---|---|
|  | 0.1 - 3.0 μm (A) | 22 - 74 μm (B) | Bulk (C) | Coal (D) | A/B | A/D | C/D |
| Arsenic | 71 | 6.4 | 17 | 1.4 | 11 | 51 | 12 |
| Lead | 79 | 12 | 20 | 1.6 | 6.6 | 49 | 12 |

ELECTROSTATIC PRECIPITATOR AND SCRUBBER PERFORMANCE ON TRACE ELEMENTS

ELECTROSTATIC PRECIPITATOR[19]

|  | Particulate | Arsenic |  | Lead |  |
|---|---|---|---|---|---|
|  |  | μg/g | mg/min. | μg/g | mg/min. |
| Inlet | 4.6 kg/min. | 130 | 598 | 110 | 506 |
| Outlet | 3.0 kg/min. | 150 | 450 | 130 | 390 |
| Efficiency % | 35 | --- | 25 | --- | 23 |

SCRUBBER[19]

|  | Particulate | Arsenic |  | Lead |  |
|---|---|---|---|---|---|
|  |  | μg/g | mg/min. | μg/g | mg/min. |
| Inlet | 4.2 kg/min. | 130 | 546 | 110 | 462 |
| Outlet | 0.34 kg/min. | 280 | 95.2 | 340 | 115.6 |
| Efficiency % | 92 | --- | 83 | --- | 75 |

ELECTROSTATIC PRECIPITATOR[20]

|  | Arsenic g/min. |  | Lead g/min. |  |
|---|---|---|---|---|
|  | 1972 | 1973 | 1972 | 1973 |
| Inlet | 1.8 | 8.1 | 7.8 | 5.9 |
| Outlet | 0.2 | 0.2 | 0.2 | 0.2 |
| Efficiency % | 88 | 97 | 97.4 | 96.6 |

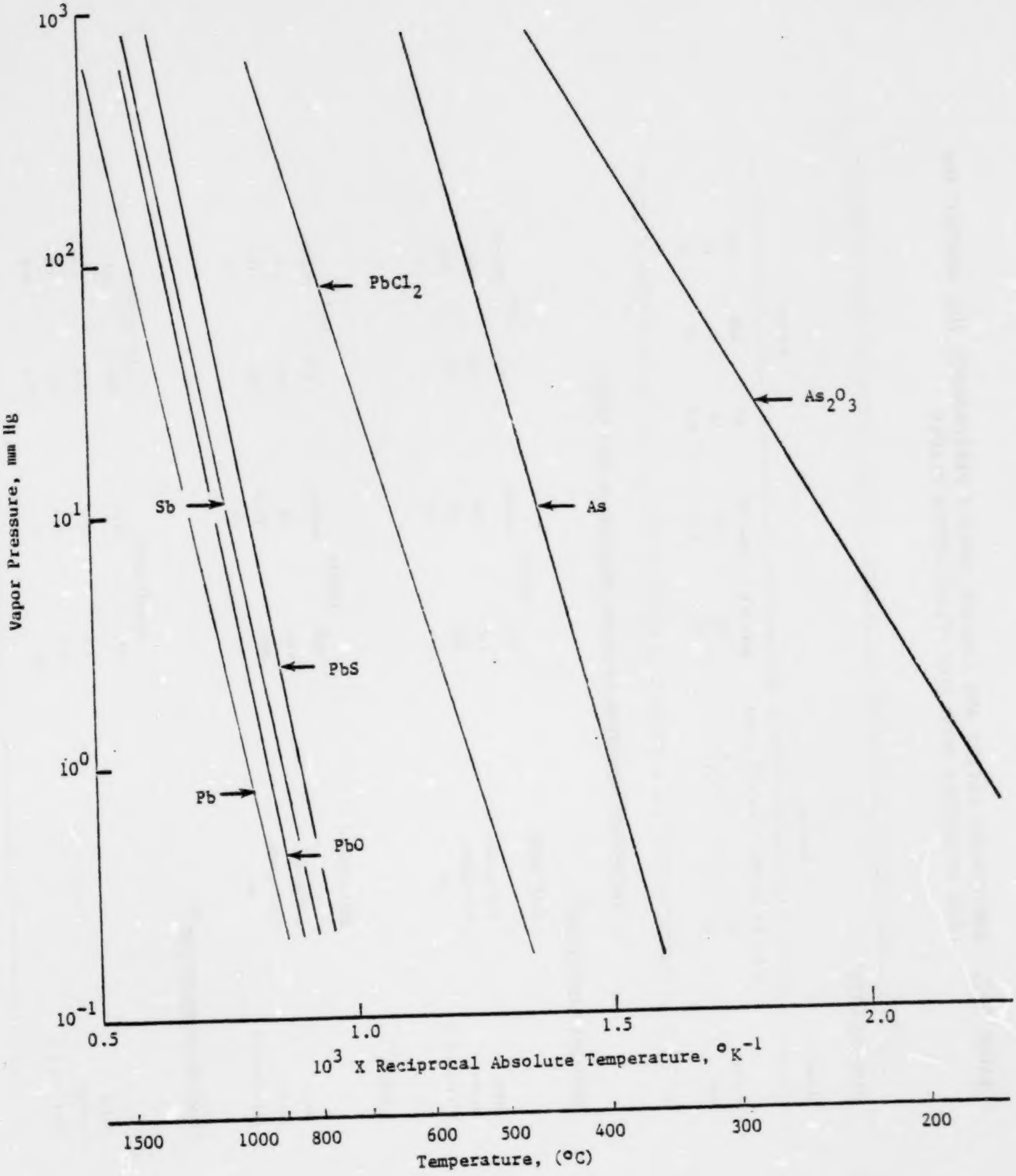

Figure 6-4. Vapor pressure of Pb, PbO, Sb, PbS, $PbCl_2$, As, and $As_2O_3$.

Several studies of particle size distribution at secondary lead smelters have been performed.[21,22] These studies have shown that the lead content of the particulate matter increased with decreasing particle size for hot emissions streams. These studies are supportive of the volatilization/condenstation mechanism, and of the extrapolations between trace element behavior in coal-fired power plants and lead and arsenic behavior in secondary lead smelters.

The use of lead emission rates as indications of arsenic emission rates from secondary lead smelters is further supported by studies of lead contamination of urban soils by emissions from secondary lead smelters.[23,24,25] These studies showed similarities in the patterns of lead and arsenic contamination around two secondary lead smelters. In addition one of these studies proposed the use of arsenic as a tracer for certain kinds of industrial lead contamination.[23]

Estimates of arsenic emission rates from secondary lead smelters were developed using measured lead emissions rates as the basis in conjunction with observed lead to arsenic contamination ratios in urban soils and vegetation surrounding secondary lead smelters. The estimation procedure is fully described in Appendix A-6. The major assumptions behind the estimation procedure are given in Table 6-8. For the purpose of this study the assumptions were chosen to maximize arsenic emissions. It should be noted that the estimated arsenic emission rates are very sensitive to changes in any of these assumptions. For example, a change in assumed lead to arsenic ratios from the upper end of the range to the lower end would decrease arsenic emissions by a factor of eight or more. Table 6-6 showed that a fabric filter/scrubber combination has lower lead emissions than a fabric filter alone. This is to be expected because the outlet temperature of the scrubber is considerably lower than the outlet temperature of the fabric filter alone and therefore more lead vapor would be condensed and captured as particulate. Chapter 2 of this report discusses the effect of temperature on arsenic removal efficiency and indicates that at lower control device temperatures, lower outlet arsenic concentrations are achievable. Arsenic and lead from combustion sources have been shown to be removed at approximately the same efficiency by a given control device. Results of a test on the arsenic and lead removal efficiency of a scrubber and ESP are given in Table 6-7. The table shows that, in general, the control devices are more efficient for arsenic removal than for lead removal. The observed lead removal efficiencies for control devices on secondary lead smelters were used to predict arsenic removal efficiencies.

6.2.2.2 Process Fugitive Emissions Sources. The major process fugitive emissions sources are the furnace charging operation, the slag tapping operations and the metal tapping operation. These operations are controlled by a combination of hoods and enclosures coupled to fabric filters at the majority of secondary lead smelters. Some secondary lead smelters use a single fabric filter to control all process fugitive emissions, and others use a separate fabric filter to control the slag

## TABLE 6-8. ESTIMATION OF ARSENIC EMISSIONS FROM PROCESS SOURCES OF SECONDARY LEAD SMELTERS

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ASSUMPTIONS FOR EXISTING EMISSIONS

- Lead to arsenic ratio in particulate emissions is 13:1 (range seen 110:1 - 13:1).
- Lead concentration in particulate matter is 42 percent (range seen 18 percent - 52 weight percent).
- Particulate concentration in fabric filter outlet is 50 $\mu g/m^3$ based on NSPS limit (test data .5 - 23 $\mu g/m^3$).
- All process fabric filters have the same outlet particulate concentration.

ASSUMPTIONS FOR FABRIC FILTER FOLLOWED BY A SCRUBBER

- Arsenic emissions will be reduced at the same efficiency as lead emissions.
- The incremental reduction of lead emissions by a fabric filter/scrubber combination over a fabric filter alone is 59 percent.

RESULTS

- Arsenic emission rates for fabric filters on blast and reverberatory furnaces are 1.6 $\mu g/m^3$.
- Arsenic emission rates for fabric filter/scrubber combinations are 0.66 $\mu g/m^3$.

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tapping operation and couple all other hoods into a single fabric filter. Fabric filters used to control process fugitive emissions are often called sanitary filters.

The emissions collected and controlled by these sanitary filters are at a much lower temperature than the emissions from the blast or reverberatory furnace. This is because the hooding and capture system entrains large volumes of ambient air as it collects the fugitive particulate emitted during the charging or tapping operations.

No arsenic test data are available for any sanitary filters. There is a limited amount of particulate and lead emissions data for these filters which indicate that they can achieve comparable particulate emission concentrations as the process fabric filters (3.6 - 24 μg/m$^3$).[21,22] In addition, the lead concentration in the particulate is approximately the same.

One study of a secondary lead smelter was performed which compared lead emissions from process, process fugitive, and area sources.[21] This study showed that lead emissions from the sanitary or process fugitive fabric filter were approximately 74 percent of the lead emissions from the fabric filter controlling process emissions. Using this study as a basis, the assumed arsenic emissions from controlled process fugitive sources were calculated. Table 6-9 presents the calculated arsenic emissions factors for process, process fugitive, and area sources for a small secondary lead smelter. Details of the calculations used to derive these figures are given in Appendix A-6.

6.2.2.3 Nonprocess or Area Fugitives. As discussed previously, there are many nonprocess fugitive sources at a typical secondary lead smelter, the majority of which are currently uncontrolled. Many States are developing State implementation plans (SIPs) to meet the NAAQS for ambient lead. These SIPs will require control of many of the area sources in secondary lead smelters. The major source of fugitive lead and arsenic emissions from a secondary lead smelter is the flue dust storage pile in the charge preparation area. These dusts which are captured by the process and sanitary filters are often stored out in the open until they can be recharged to the reverberatory furnace. The material is fine and easily entrained by the wind. A study has been made of lead fugitive sources around a secondary lead smelter.[21] Table 6-10 reports the results of this study. The table shows that the charge preparation area is the largest contributor to nonprocess fugitive lead emissions, and that the battery breaking area is also an important source. No arsenic emissions test data are available for nonprocess fugitive sources of secondary lead smelters. Arsenic emissions factors for area sources were estimated in the same manner as for process fugitive sources. A comparison of the uncontrolled area sources to the controlled process sources showed that the nonprocess fugitive lead emissions were 1.7 times larger than the controlled process

TABLE 6-9. ARSENIC EMISSIONS FACTORS FOR A SMALL SECONDARY LEAD SMELTER

| SOURCE | PROCESS | PROCESS FUGITIVE | AREA |
|---|---|---|---|
| Emission Point | Blast & Reverberatory Furnaces | Furnace Charging & Tapping | Material Storage Areas & Haul Roads |
| Control Device | Fabric Filter | Fabric Filter | None |
| Emission Factor | | | |
| g/kg lead produced | 0.036 | 0.028 | 0.06 |
| lb/ton lead produced | 0.072 | 0.054 | 0.12 |

## TABLE 6-10. NONPROCESS FUGITIVE LEAD EMISSIONS AT A TYPICAL LARGE LEAD SMELTER[21]

| EMISSIONS SOURCE | LEAD EMISSION RATE g/hr | % |
|---|---|---|
| Battery Storage Areas | 106 | 8.3 |
| Battery Breaking Yard | 260 | 20.5 |
| Charge Makeup Area | 400 | 31.5 |
| Slag Storage Area | 235 | 18.5 |
| Smelter Access Road (workday) | 41 | 3.2 |
| Building Fugitives[a] | 228 | 18 |
| TOTAL Nonprocess Fugitives | 1,270 | 100% |

lead emissions. This factor was then used to estimate nonprocess fugitive arsenic emission rates for a model smelter.

## 6.3 DEFINITION OF EBC OPTIONS

This section discusses the estimated best control technology (EBC) for control of arsenic emissions from secondary lead smelters. The section will be divided into three parts which will discuss the availability of EBC options for process, process fugitive and nonprocess fugitive sources in turn. Each section will address, where applicable, the arsenic removal potential of the identified EBC option, the technical feasibility of EBC and identify existing plants currently using the EBC option.

### 6.3.1 Process Sources

Blast and reverberatory furnaces are currently controlled by either fabric filters or fabric filters followed by scrubbers. In Section 6.2 it was shown that the fabric filter/scrubber combination had lower lead emissions than the fabric filter alone. In addition, several studies were discussed which showed that it was reasonable to assume that lead behavior could be used as an indication of arsenic behavior. For the purpose of this study the combination system of fabric filter followed by a scrubber will be chosen as the EBC option for further study. Using the data presented in Section 6.2 the estimated incremental arsenic removal efficiency of the combination system over the fabric filter alone is 59 percent.

There are no technological problems associated with following a fabric filter with a scrubber. Five secondary lead smelters currently use scrubbers after their fabric filters to control $SO_2$ emissions from their smelting furnaces.[26] Retrofiting existing secondary lead smelters with a scrubber or scrubbers may be difficult because of space limitations at the plant. These problems are not insurmountable but may increase the costs of applying a scrubber over the costs expected for control of new sources. Use of a scrubber will result in a wastewater treatment problem in addition to a solid disposal problem. Any scrubber liquor which is blown down will have to be treated and disposed of. Existing plants currently have to treat any acidic liquid waste derived from the battery crushing operation or battery storage areas. However, the treatment system for these acidic wastes may not be applicable to the scrubber blowdown.

Existing plants currently recycle all captured particulate matter to the smelting furnaces. It may be possible to do the same with the scrubber generated sludges if the material can be dewatered and if the scrubber is not used for $SO_2$ control. If the scrubber is used for joint control of $SO_2$ and arsenic then large quantities of calcium sulfite and sulfate sludges will be generated. These materials cannot be recycled to the smelting furnaces, and must be disposed of. Several existing plants are currently landfilling this material on site.

### 6.3.2 Process Fugitives

All existing process fugitive sources of secondary lead smelters are controlled by fabric filters operating at low temperatures [below 37°C (100°F)]. Further cooling of these streams to increase arsenic removal efficiency is not feasible. For this reason EBC is assumed to be in place.

### 6.3.3 Nonprocess Fugitives

The majority of nonprocess fugitive emission sources are currently uncontrolled. However, because of the NAAQS for lead, most States are revising their SIPs for lead, and it is anticipated that these revisions will require tight control of all nonprocess fugitive sources at secondary lead smelters. The controls which will have to be implemented to achieve a boundary line lead concentration of 1.5 $\mu g/m^3$ will be EBC for lead and for arsenic.

## 6.4 DETERMINATION OF THE INCREMENTAL IMPACTS OF EBC

The purpose of this section is to discuss the incremental impacts associated with applying the EBC options identified in Section 6.3 to typical smelters in secondary lead industry. The section is divided into four parts. These are model plants, incremental impacts, population exposure assessment, and economic impacts.

### 6.4.1 Model Plants

Three model secondary lead smelters have been developed in this study. These are described in Tables 6-11 and 6-12. These model plants will be used in the ambient modeling associated with the exposure analysis, and as the basis for determining the potential impacts of applying EBC options to any of the sources considered. Model plants were used in this study because it was not feasible to individually analyze all 66 secondary lead smelters in the U.S.

As can be seen from the tables, all three source types, process, process fugitive, and area fugitives will be considered in the exposure analysis. However, only the process sources will be considered for the incremental impact analysis for EBC since the two fugitive sources will have EBC in place when they come into compliance with all existing regulations.

The model plant parameters presented in the tables were derived from a survey of the NEDS data, telephone contacts, and from trip reports made as part of the NSPS revisions for secondary lead smelters. Arsenic emissions estimates presented in Table 6-12 are based solely on calculations and engineering judgement and therefore should be used with caution. Appendix A to this report discusses the assumptions used to derive the emission factors presented. As can be seen in the appendix, the emission rates used are sensitive to any changes in the assumptions used. For example, changing the

## TABLE 6-11. MODEL PLANT PARAMETERS

| PLANT SIZE | LEAD PRODUCTION Mg/yr (tpy) | LEAD PRODUCTION Mg/hr (tph) | HOURS OF OPERATION | EMISSION SOURCE | CONTROL DEVICE EXISTING | CONTROL DEVICE BASELINE | CONTROL DEVICE EBC |
|---|---|---|---|---|---|---|---|
| Small | 9,090 (10,000) | 1.5 (1.7) | 6,000 | Process | Single FF[a] | Single FF | FF/Scrubber |
| | | | | Process Fugitive | Single FF | Single FF | Single FF |
| | | | | Area | Uncontrolled | Not Defined | |
| Medium | 18,180 (20,000) | 3 (3.3) | 6,000 | Process | Single FF | Single FF | FF/Scrubber |
| | | | | Process Fugitive | Single FF | Single FF | Single FF |
| | | | | Area | Uncontrolled | Not Defined | |
| Large | 36,360 (40,000) | 6.1 (6.7) | 6,000 | Process | 2 FF's | 2 FF's | 2 FF/Scrubbers |
| | | | | Process Fugitive | Single FF | Single FF | Single FF |
| | | | | Area | Uncontrolled | Not Defined | |

[a] FF = fabric filter.

## TABLE 6-12. MODEL PLANT EMISSION PARAMETERS

| | | STACK PARAMETERS | | | | | ARSENIC EMISSIONS | |
|---|---|---|---|---|---|---|---|---|
| Model Plant Number & Size | Emission Points | Height m (ft) | Diameter m (ft) | Exit Temp. K (°F) | Flow Rate $m^3$/sec (acfm) | Velocity m/sec (fps) | Baseline kg/hr (lb/hr) | EBC kg/hr (lb/hr) |
| 1. Small[e] | Process baghouse | 31 (100) | .62 (2) | 351 (175) | 9.44 (20,000) | 29.0 (95) | .05 (.12)[a] | .02 (.05)[c] |
| | Process fugitives | 15.4 (50) | 1.2 (4) | 302 (85) | 23.6 (50,000) | 20.1 (66) | .04 (.09)[a] | .04 (.09)[c] |
| | Area fugitives[d] | | | Area Source 3,344 $m^2$ (36,000 $ft^2$) | | | .09 (.2) | -[h] |
| 2. Medium[f] | Process baghouse | 31 (100) | .92 (3) | 351 (175) | 17 (36,000) | 25.9 (85) | .09 (.2)[a] | .04 (.08)[c] |
| | Process fugitives | 15.4 (50) | 1.2 (4) | 302 (85) | 30.7 (65,000) | 26.2 (86) | .05 (.12)[a] | .05 (.12) |
| | Area fugitives | | | Area Source 6,744 $m^2$ (72,000 $ft^2$) | | | .15 (0.4)[b] | -[h] |
| 3. Large[g] | Process baghouse (1) | 26 (85) | 1.2 (4) | 355 (180) | 17 (36,000) | 16.6 (48) | .09 (.2)[a] | .04 (.08)[c] |
| | Process baghouse (2) | 26 (85) | 1.2 (4) | 355 (180) | 17 (36,000) | 16.6 (48) | .09 (.2)[a] | .04 (.08)[c] |
| | Process fugitives | 15.4 (50) | 1.53 (5) | 302 (85) | 37.8 (80,000) | 20.7 (68) | .14 (.30) | .14 (.30) |
| | Area fugitives | | | Area Source 13,470 $m^2$ (145,000 $ft^2$) | | | .32 (.70)[b] | -[h] |

[a] Baseline control is a fabric filter.

[b] No controls in place.

[c] EBC controls for process sources is a fabric filter followed by a venturi scrubber.

[d] Area fugitives assumed to originate from storage and charge prep area with dimensions shown.

[e] Small plant - 10,000 tons Pb produced/year; 6,000 operating hr/yr.

[f] Medium plant - 20,000 tons Pb produced/year; 6,000 operating hr/yr.

[g] Large plant - 40,000 tons Pb produced/year; 6,000 operating hr/yr. Two process baghouses operating at the same time.

[h] EBC rates will be required by OSHA standard and Lead NAAQS. Arsenic emissions cannot be quantified under this scenario. For the purposes of the exposure analysis area fugitives can be assumed to be equal to baseline conditions.

assumed lead to arsenic ratio from 13:1 to 110:1 will change the emissions by a factor of eight.

Process fugitive emissions and nonprocess emissions are based on the ratio of lead emissions from these sources to the amount of lead emitted from process sources for a single plant. These arsenic emissions estimates are therefore even more tenuous than the estimates of process emissions.

### 6.4.2 Incremental Impact of EBC Options for Process Emissions

As discussed previously the blast and reverberatory furnaces in a typical lead smelter are currently controlled by an afterburner, cooler and fabric filter or cooler and fabric filter to meet the applicable NSPS or SIP particulate regulation. The EBC option to be evaluated involves following the existing fabric filter by a scrubber. The incremental impacts of the EBC option can therefore be determined by looking at the impacts associated with the scrubber alone.

The capital and operating costs associated with the use of a scrubber are shown in Table 6-13. The table shows that the capital costs will range from $209,000 to $594,000 depending upon plant size, and the annualized costs will range from $127,000 to $371,000. These estimates were derived from cost data presented by MRI in their project conclusions report for the secondary lead NSPS revision.[8] Details of the derivation of the costs used in this study are given in Appendix B-6. All costs have an accuracy of ±40 percent at best.

The energy and water consumption of the scrubber system is also given in Table 6-13 for each model plant size. The table also shows the estimates of the amounts of solid waste that would be generated by a water scrubber used to control arsenic emissions. If the scrubber were installed for joint $SO_2$ and arsenic control then the quantities of arsenic containing solid waste would be much greater.

The nationwide impacts of applying the EBC option to all existing smelters are shown in Table 6-14. The table shows that an arsenic emissions reduction of 22.4 Mg (24.6 tons)/yr could be achieved by applying the EBC options.

### 6.4.3 Economic Impact of EBC

An economic impact analysis was conducted for the secondary lead smelting plants to estimate the potential impact of requiring EBC technology. Using the cost data in Table 6-13 and the methodology given in Appendix C, revenue and product price increases, required by smelters to maintain the same net present values before and after the installation of EBC, were estimated. To test the sensitivity of the economic impact results to the various input data, a sensitivity analysis was conducted for the secondary lead model plants, assuming simultaneous 15 percent decreases in

TABLE 6-13. CAPITAL AND OPERATING COSTS FOR CONTROL OF ARSENIC EMISSIONS FROM SECONDARY LEAD PROCESS SOURCES

| | PLANT SIZE | | |
|---|---|---|---|
| | Small | Medium | Large |
| Flow $m^3$/sec (dscfm) | 9.64 (20,000) | 17 (36,000) | 34 (72,000) |
| Total Installed Cost | $ 209,000 | $ 297,000 | $ 594,000 |
| Annualized Capital Cost @ .13147[a] | 27,477 | 39,047 | 78,093 |
| Operating Labor | 18,100 | 18,100 | 36,200 |
| General Maintenance @ 11% of TIC | 22,990 | 32,670 | 65,340 |
| Electricity Costs for fan and pump | 31,000 | 56,000 | 112,000 |
| Water | 425 | 2,150 | 4,300 |
| Overhead | 18,200 | 25,862 | 51,724 |
| Property tax and insurance @ 4% | 8,360 | 11,880 | 23,760 |
| Total Annualized Cost | $127,000 | $186,000 | $371,000 |
| Arsenic Removal kg/yr (pounds/year) | 191 (420) | 327 (720) | 655 (1,440) |
| Energy Consumption Mj/yr ($10^3$ kWh) | 2,808 (780) | 5,011 (1,392) | 10,000 (2,778) |
| Water Consumption $10^3$ $M^3$/yr (M gal/yr) | 6.4 (1.7) | 11.7 (3.1) | 23.5 (6.2) |
| Solid Waste Generation Mg/yr (TPY) | 20 (22) | 34 (37.5) | 68 (75) |

[a] 10% interest for 15 years.

TABLE 6-14. NATIONWIDE IMPACTS OF APPLYING EBC TO ALL PROCESS SOURCES[a]

| | |
|---|---|
| Total Capital Cost $ | $21,600,000 |
| Total Annualized Cost $ | 13,400,000 |
| Arsenic Removal Mg/yr | 22.4 |
| Energy Consumption Mj/yr | 338,000 |
| Water $10^3 M^3$/yr | 790 |
| Solid Waste Mg/yr | 2,300 |

[a] Based upon 18 large plants, 12 medium plants and 35 small plants.

baseline price and annual output and a 15 percent increase in the weighted cost of capital.

The annual revenue increases required by the secondary lead smelter model plants to maintain their profitability range from $127,000 in the small model plant to $370,000 in the large model plant. These additional revenues would require product price increases of between 10¢ and 15¢ per kg (4.5 - 6.8¢ per lb). Percentage product price increases ranging from 1.1 to 1.6 percent would be required to maintain profitability. The revenue and price impacts for the secondary lead model plants are summarized in Table 6-15.

Under the conditions of the sensitivity analysis the small model plant would require a unit price increase of 17¢ per kg (7.7¢ per lb), while the medium and large plants would require a 12¢ per kg (5.5¢ per lb) increase. Percentage price increases in the secondary lead models rose to 2.2 percent in the small model plant and 1.6 percent in the medium and large model plants. The sensitivity analysis results are summarized in Table 6-16.

## 6.5 POPULATION EXPOSURE DATA

The data in Tables 6-12 and 6-17 were developed during this study for use in an air pollution dispersion model to estimate the population exposure to arsenic from secondary lead smelting plants. The Strategies and Air Standards Division (SASD) of EPA is using these data in an ongoing effort to estimate exposure to arsenic from this source category.

## 6.6 EASE OF STANDARDS DEVELOPMENT

The biggest impediment to developing standards to limit arsenic emissions from secondary lead smelters is the lack of actual arsenic test data for all of the sources at a typical smelter. As discussed in this chapter, the arsenic emissions estimates are sensitive to changes in any of the assumptions. In addition, arsenic emissions from any two smelters cannot be expected to be the same because of the wide variations in the arsenic contents of the feed materials and the variations in operating practices. The only way to address this problem adequately would be to test several smelters operating at different conditions and utilizing different feed materials.

An additional problem involves the control of area fugitive sources around secondary lead plants. Emissions from these sources are difficult to quantify, the current status of control is difficult to determine and the level of control which will be required by the revised SIPs for the lead NAAQS is hard to assess.

## TABLE 6-15. REVENUE AND PRICE IMPACTS FOR SECONDARY LEAD SMELTERS TO ACHIEVE EBC

| MODEL PLANT | REQUIRED REVENUE INCREASE (000 dollars) | REQUIRED UNIT PRICE INCREASE (dollars per kg) | REQUIRED PERCENT UNIT PRICE INCREASE |
|---|---|---|---|
| Small | 126.9 | .014 | 1.6 |
| Medium | 185.2 | .010 | 1.1 |
| Large | 370.4 | .010 | 1.1 |

TABLE 6-16. SENSITIVITY ANALYSIS OF THE REVENUE AND PRICE INCREASES FOR SECONDARY LEAD SMELTERS

| MODEL PLANT | REQUIRED REVENUE INCREASE (000 dollars) | REQUIRED UNIT PRICE INCREASE (dollars per kg) | REQUIRED PERCENT UNIT PRICE INCREASE |
|---|---|---|---|
| Small | 130.0 | .017 | 2.2 |
| Medium | 189.6 | .012 | 1.6 |
| Large | 379.2 | .012 | 1.6 |

TABLE 6-17. EXISTING PLANT LOCATIONS AND CONTROL STATUS[a]

|  | UTM Grid Coordinates |  |  |  | Control Status of Emission Points |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| Plant Location | Zone | Horizontal (km) | Vertical (km) | Model Plant[b] Size | Process Baseline[c] | Process EBC | Process Fugitive EBC | Area Fugitives Existing[d] | Area Fugitives EBC |
| Interstate Lead Co., Inc.<br>Leeds, AL | 16 | 543.3 | 3,717.7 | Medium | X |  | X | X |  |
| Sanders Lead Company<br>Troy, AL | 16 | 596.7 | 3,517.5 | Large | X |  | X | X |  |
| RSR Corporation<br>City of Industry, CA |  |  |  | Large |  | X | X | X |  |
| ALCO Mining, Inc.<br>Gardena, CA | 11 | 379.5 | 3,744.9 | Small |  | X | X | X |  |
| South West Metal<br>San Bernardino, CA | 11 | 471.5 | 3,772.6 | Small |  | X | X | X |  |
| ASARCO<br>San Francisco, CA |  |  |  | Small | X |  | X | X |  |
| Gould, Inc.<br>Vernon, CA | 11 | 407.5 | 3,764 | Medium | X |  | X | X |  |
| National Smelting & Refining<br>Denver, CO | 13 | 507.8 | 4,404.9 | Small | X |  | X | X |  |
| Refined Metals Corp.<br>Jacksonville, FL | 17 | 431.8 | 3,358.3 | Medium | X |  | X | X |  |
| Globe Union, Inc.<br>Tampa, FL | 17 | 359.9 | 3,102.5 | Large | X |  | X | X |  |

TABLE 6-17. (Continued) EXISTING PLANT LOCATIONS AND CONTROL STATUS[a]

| Plant Location | Zone | UTM Grid Coordinates Horizontal (km) | UTM Grid Coordinates Vertical (km) | Model Plant[b] Size | Control Status of Emission Points: Process Baseline[c] | Control Status of Emission Points: Process EBC | Control Status of Emission Points: Process Fugitive EBC | Control Status of Emission Points: Area Fugitives[d] Existing | Control Status of Emission Points: Area Fugitives[d] EBC |
|---|---|---|---|---|---|---|---|---|---|
| Industrial Smelting Co.<br>Detroit, MI | 17 | 332.4 | 4,677.2 | Small | Not Applicable | | X | X | |
| TARACORP Industries<br>St. Louis Park, MN | 15 | 471.2 | 4,975.8 | Small | X | | X | X | |
| Gopher Smelting & Refining Co.<br>St. Paul, MN | 15 | 490.7 | 4,964.4 | Medium | X | | X | X | |
| Chloride Metals, Inc.<br>Florence, MS | 15 | 772.4 | 3,561.1 | Small | X | | X | X | |
| Schuykill Metals<br>Forest City, MO | | | | Large | X | | X | X | |
| Gould, Inc.<br>Omaha, NE | 15 | 255.1 | 4,571.2 | Medium | X | | X | X | |
| Delco Remy Battery<br>New Brunswick, NJ | 18 | 545.2 | 4,481.1 | Small | X | | X | X | |
| Essex Metal Alloys<br>Newark, NJ | 18 | 571.8 | 4,509.0 | Small | Not Applicable[e] | | X | X | |
| Aetna Alloys Division<br>Newark, NJ | | | | Small | Not Applicable | | X | X | |
| NL Industries<br>Pedricktown, NJ | 18 | 463.6 | 4,400.8 | Large | X | | X | X | |

TABLE 6-17. (Continued) EXISTING PLANT LOCATIONS AND CONTROL STATUS[a]

| Plant Location | UTM Grid Coordinates | | | Model Plant[b] Size | Control Status of Emission Points | | |
|---|---|---|---|---|---|---|---|
| | Zone | Horizontal (km) | Vertical (km) | | Process Baseline[c] EBC | Process Fugitive EBC | Area Fugitives Existing[d] EBC |
| Gulf Coast Lead Co.<br>Tampa, FL | | | | Large | X | X | X |
| NL Industries, Inc.<br>Atlanta, GA | 16 | 740.3 | 3,741.9 | Medium | X | X | X |
| TARACORP<br>Atlanta, GA | | | | Medium | X | X | X |
| Sanders Lead Co.<br>Cedartown, GA | | | | Medium | X | X | X |
| Chloride Metals<br>Columbus, GA | 16 | 639.9 | 3,590.3 | Large | X | X | X |
| TARACORP<br>Granite City, IL | 15 | 747.2 | 4,286.8 | Medium | X | X | X |
| TARACORP<br>McCook, IL | 16 | 433.4 | 4,628.3 | Small | X | X | X |
| North Chicago Smelting & Refining<br>North Cook, IL | | | | Small | Not Applicable | X | X |
| Refined Metals Corp.<br>Beach Grove, IN | 16 | 580.2 | 4,395.8 | Large | X | X | X |
| USS Lead Refining, Inc.<br>E. Chicago, IN | | 461.4 | 4,607.1 | Large | X | X | X |

TABLE 6-17. (Continued) EXISTING PLANT LOCATIONS AND CONTROL STATUS[a]

| | | UTM Grid Coordinates | | | Control Status of Emission Points | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Process Fugitive | Area Fugitives | |
| Plant Location | Zone | Horizontal (km) | Vertical (km) | Model Plant[b] Size | Process Baseline[c] | Process EBC | EBC | Existing[d] | EBC |
| Northern Indiana Dock Co.<br>E. Chicago, IN | | 464.1 | 4,612.0 | Small | X | | X | X | |
| RSR-Quemetco Corp.<br>Indianapolis, IN | | 557.8 | 4,400.3 | Large | X | | X | X | |
| Mincon(sold to Bergsoe)<br>Muncie, IN | | 635.0 | 4,446.0 | Large | X | | X | X | |
| ASARCO<br>Whiting, IN | | | | Small | X | | X | X | |
| Delco Remy Battery<br>Olathe, KS | | | | Small | X | | X | X | |
| Schuykill Metals Corp.<br>Baton Rouge, LA | 15 | 668.5 | 3,384.9 | Large | X | | X | X | |
| General Battery Corp.<br>Heflin, LA | | | | Small | X | | X | X | |
| Sommerville Smelting<br>Sommerville, MA | | | | Small | X | | X | X | |
| New England Smelting Works<br>W. Springfield, MA | | | | Small | Not Applicable | | X | X | |
| Federal Alloys<br>Detroit, MI | | (Shutdown) | | Small | Not Applicable | | X | X | |

TABLE 6-17. (Continued) EXISTING PLANT LOCATIONS AND CONTROL STATUS[a]

| | | UTM Grid Coordinates | | | Control Status of Emission Points | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Process | | Process Fugitive | Area Fugitives | |
| Plant Location | Zone | Horizontal (km) | Vertical (km) | Model Plant[b] Size | Baseline[c] | EBC | EBC | Existing[d] | EBC |
| E. L. Beth<br>Perth Amboy, NJ | 18 | 562.5 | 4,484.7 | Small | X | | X | X | |
| CAL-WEST<br>Socorro, NM | | | | Small | Not Applicable | | X | X | |
| Republic Metals<br>Brooklyn, NY | | 588.2 | 4,509.4 | Small | X | | X | X | |
| Roth Bros. Smelting Corp.<br>Dewitt, NY | | | | Small | X | | X | X | |
| Willard Lead Co.<br>Charlotte, NC | 17 | 511.7 | 3,894.4 | Small | X | | X | X | |
| Master Metals, Inc.<br>Cleveland, OH | 17 | 443.2 | 4,592.2 | Medium | X | | X | X | |
| River Smelting & Refining<br>Cleveland, OH | | | | Small | Not Applicable | | X | X | |
| Lancaster Battery Co.<br>Lancaster, PA | 18 | 386.5 | 4,434.3 | Small | X | | X | X | |
| East Penn Manufacturing Co.<br>Lyons Station, PA | 18 | 435.0 | 4,480.2 | Small | X | | X | X | |
| Tonolli Corp.<br>Nesquehoning, PA | 18 | 425.6 | 4,522.1 | Large | | X | X | X | |

TABLE 6-17. (Continued) EXISTING PLANT LOCATIONS AND CONTROL STATUS[a]

| Plant Location | UTM Grid Coordinates |  |  | Model Plant[b] Size | Control Status of Emission Points |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | Zone | Horizontal (km) | Vertical (km) |  | Process Baseline[c] | Process EBC | Process Fugitive EBC | Area Fugitives Existing[d] | Area Fugitives EBC |
| Gould, Inc. Philadelphia, PA | 18 | 492.6 | 4,427.8 | Small | X |  | X | X |  |
| Imperial Metal Co. Philadelphia, PA | 18 | 491.3 | 4,426.5 | Small | X |  | X | X |  |
| General Battery Corp. Reading, PA | 18 | 417.6 | 4,489.1 | Large |  | X | X | X |  |
| Marjol Battery Corp. Throop, PA |  |  |  | Medium | Not Applicable |  | X | X |  |
| General Smelting & Refining College Grove, TN | 16 | 530.1 | 3,961.6 | Small | X |  | X | X |  |
| Refined Metals Corp. Memphis, TN | 15 | 766.9 | 3,886.4 | Large | X |  | X | X |  |
| Ross Metals, Inc. Rossville, TN | 16 | 265.1 | 3,880.9 | Small | X |  | X | X |  |
| General Battery Corp. Dallas, TX | 14 | 708.3 | 3,625.2 | Medium | X |  | X | X |  |
| RSR Corporation Dallas, TX | 14 | 688.7 | 3,626.2 | Large | X |  | X | X |  |
| NL Industries, Inc. Dallas, TX | 14 | 707.9 | 3,626.7 | Small | X |  | X | X |  |

TABLE 6-17. (Continued) EXISTING PLANT LOCATIONS AND CONTROL STATUS[a]

| Plant Location | UTM Grid Coordinates | | | Model Plant[b] Size | Control Status of Emission Points | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Zone | Horizontal (km) | Vertical (km) | | Process Baseline[c] | EBC | Process Fugitive EBC | Area Fugitives Existing[d] | EBC |
| Gould, Inc.<br>Frisco, TX | 14 | 702.5 | 3,669.1 | Large | X | | X | X | |
| Houston Lead Co.<br>Houston, TX | | (Shutdown) | | Small | X | | X | X | |
| Standard Industries<br>San Antonio, TX | | | | Small | Not Applicable | | X | X | |
| Hyman Viener & Sons<br>Richmond, VA | 18 | 287.3 | 4,154.3 | Medium | X | | X | X | |
| RSR Corporation<br>Seattle, WA | 10 | 548.7 | 5,269.6 | Large | X | | X | X | |
| Crown Metal<br>Milwaukee, WI | | | | Small | Not Applicable | | X | X | |

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[a] Information compiled from the Lead Industries Association, a NEDS listing, State air pollution control agency contacts.

[b] Large = 25,000 tons/yr; 125 tons/day.
Medium = 15,000-25,000 tons/yr; 50-125 tons/day.
Small = 15,000 tons/yr; 50 tons/day.

[c] Baseline is that level of control required by existing SIPs or NSPS.

[d] Existing level of control for area fugitives does not reflect compliance with NAAQS for lead.

[e] Control status not applicable; pot furnaces only; no blast or reverberatory units.

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# 7.0 COTTON GINS

This chapter discusses the cotton ginning industry and its associated arsenic emissions. Section 7.1 presents a brief source category description. Section 7.2 discusses the regulations currently covering the industry and the resulting level of control and associated arsenic emissions. Section 7.3 presents a discussion of the estimated best control (EBC) options and Section 7.4 discusses the impacts of applying these options. Section 7.5 presents the input data to be used in assessing the population exposure to arsenic emissions from cotton ginning. The ease of standards development is discussed in Section 7.6.

## 7.1 SOURCE DESCRIPTION

### 7.1.1 Arsenic Acid Desiccation

The only cotton gin operations of concern in this study are those which handle and gin cotton that has been desiccated with orthoarsenic (arsenic) acid ($H_3AsO_4$). Approximately 98 percent of all cotton that is treated with arsenic acid is grown in Texas, with the remainder grown in Oklahoma.[1,2] As a result, certain cotton gins in these two States have the potential to emit inorganic arsenic during normal operations. For both States combined, an average of 8.5 billion $m^2$ (2.1 million acres) of cotton are treated with arsenic acid every year.[3,4,5] Estimates of the number of cotton gins processing the desiccated cotton range from 285 to 320.[2,6] In Texas several designated areas, including the Blacklands (which is the most significant source), the Coastal Bend, and the Lower or Rolling Plains constitute the major sources of arsenic acid-desiccated cotton and arsenic emitting cotton gins.[5,7,8,9] The High Plains area of Texas generally relies on winter frost freezes to perform the function of an arsenic acid desiccant, and uses comparatively minor amounts of arsenic acid.[5,6,9,10,11] In some years a killing frost may desiccate cotton in areas outside of the High Plains, but this is not common and cannot be relied upon. The southwest corner of Oklahoma is the primary desiccated cotton area for that state.[3,8] Figure 7-1 depicts the main areas of arsenic acid usage.

The use of arsenic acid as a cotton desiccant was first begun in 1956.[5] It replaced pentachlorophenol (PCP) as the standard cotton desiccant. The use of PCP declined because PCP manufacturers discovered that they had a larger and more profitable market available in the area of wood preserving. The shift of the PCP supply to the wood preservers, combined with the lower cost and equivalent effectiveness of arsenic acid tended to gradually phase out PCP use as a desiccant.[12]

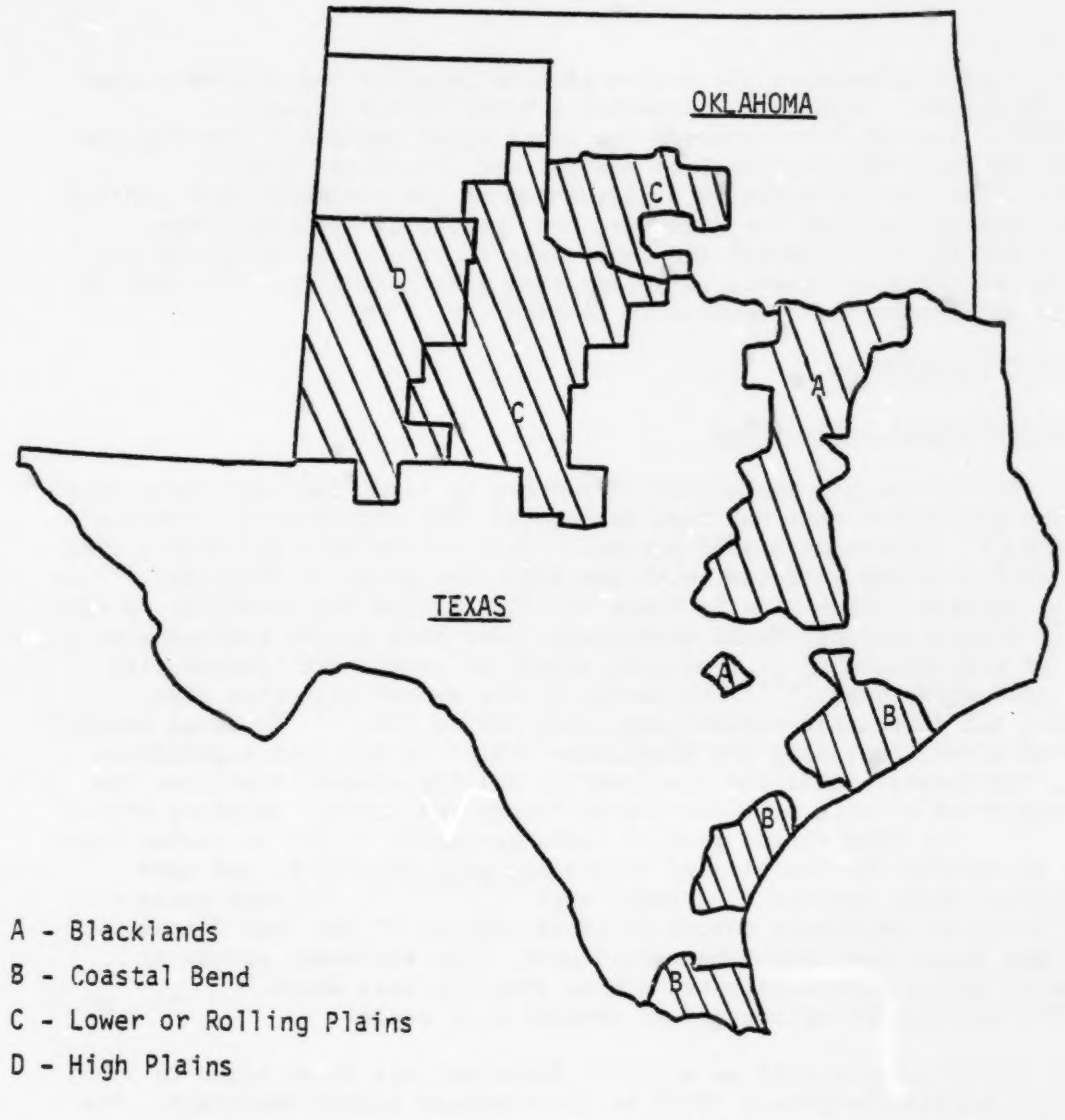

OKLAHOMA
C
D
C
A
TEXAS
A
B
B
B
A - Blacklands
B - Coastal Bend
C - Lower or Rolling Plains
D - High Plains

Figure 7-1. Primary areas of arsenic acid desiccation.

In the non-irrigated areas of Texas and Oklahoma, a concept of cotton production known as short-season cotton has evolved. Consistently low cotton yields in these areas necessitated the development of a production system that uses specially-bred, short-season varieties of cotton in which the bolls mature early and at the same time so that once-over harvesting is possible.[11] The use of once-over harvesting required that an efficient harvesting method known as mechanical stripping be developed. A mechanical stripping operation essentially removes all parts of the cotton plant including the leaves, burs, bolls, and side branches and leaves only a bare stalk.

The quantity of trash generated by mechanical stripping has been reported to range from 325 to 545 kg (715 to 1199 lb) per bale of lint cotton produced, with the average trash content being 360 kg (792 lb). Of the total amount of seed cotton harvested by stripping, approximately 35 to 40 percent will be trash.[13,14,15,16,17] A range of trash content exists because the level of trash and foreign matter in the seed cotton increases as the harvest season progresses.[18] Because the arsenic acid is associated with the plant material, the more trash in the seed cotton, the greater the potential level of inorganic arsenic emissions.

Today's varieties of short-season cotton have been specifically adapted for stripper harvesting. However, a desiccant must be applied to short-season cotton prior to stripper harvesting to dry out green plant leaves to prevent fiber staining and unacceptable levels of fiber moisture content. The addition of green leaves to the seed cotton increases fiber moisture, thereby creating a condition in which the cotton will heat during storage and be lowered in quality prior to ginning.[3,4] It is recommended that the fiber moisture be less than 12 percent, with an optimum range being 6.5 to 9.5 percent.[4,5,19] Overdrying must be avoided, however, because lint quality can be lowered.[4]

### 7.1.2 Methods of Desiccant Application

Arsenic acid for cotton desiccation is always applied as a spray. About 20 to 30 percent of the material is applied by aircraft and the rest by ground sprayers. Both self-propelled, high-clearance machines and tractor-mounted sprayers are used for ground application. Generally, 1.4 liters (3 pints) of arsenic acid are diluted to a final volume of about 37.9 liters (10 gal) of spray solution per acre. Where aircraft are used, 1.4 liters (3 pints) are applied in a total spray volume of 11.4 to 18.9 liters (3 to 5 gal) per acre. The active ingredient of the spray solution does not dry out prior to leaf penetration because the droplets are hygroscopic in nature. The arsenic acid solution desiccates the cotton plant by disrupting the cell membranes such that natural drying of leaf and stem tissues occurs.[5]

### 7.1.3 Factors Affecting Potential Inorganic Arsenic Emissions Prior to Ginning

7.1.3.1 Occurrence of a Killing Frost. Several factors dictate the need to desiccate stripper cotton. If the cotton growing regions receive a killing frost [-2°C (28°F) or less] at the correct point in the harvest season, no arsenic acid desiccation is needed. Unfortunately this situation does not occur in the majority of stripper areas, and therefore, cannot be relied on for desiccation purposes. The sales records of one arsenic acid manufacturer to cotton harvesters showed a range of consumption from 2.5 to 6.2 million kg (5.5 to 13.7 million lbs) during the period from 1964 to 1977.[20,21] However, during this period sales to the Blacklands and Coastal Bend regions showed little variability indicating that the Texas Plains and Oklahoma growing regions experience the most killing frosts and account for the considerable fluctuation witnessed in arsenic acid consumption over the 1964 to 1977 period.

7.1.3.2 Arsenic Acid Shortages. Potential arsenic acid emissions from cotton ginning may be reduced because of a shortage of the acid for desiccation purposes in some or all of the cotton growing regions. The shortage can be caused by the inability of the arsenic acid suppliers to produce enough arsenic acid or by the suppliers preferential sale of the acid to other consumers, primarily wood preservative manufacturers. An example of the first type of shortage occurred in 1977 due to a labor strike at the sole U.S. plant producing arsenic trioxide, the chief raw material for arsenic acid. When this situation occurred cotton growers were forced into using the only other registered desiccant, paraquat. The second type of shortage occurs because arsenic acid manufacturers prefer to sell most of their product to the wood preservative manufacturing industry.[22,23] They prefer the wood preservative business because it represents a constant demand unlike the cotton desiccation use which is seasonal in nature. One arsenic acid manufacturer indicated that cotton growers actually only receive the product that cannot be sold to wood preservative companies.[22]

7.1.3.3 Meteorological Conditions. The growth rate of the cotton plant is the most important variable in determining how much arsenic acid is needed for desiccation, and consequently may be emitted during ginning. Plant growth is directly related to soil and meteorological conditions, such as soil moisture, air temperature, and quantity of rainfall. If temperatures have been warm and rainfall plentiful, the cotton plant will grow to be very sturdy. As a result, desiccation is more difficult and greater quantities of arsenic acid are required for the job. Multiple applications may even be required, particularly when second-growth or regrowth leaves appear on the plant.[4,24,25]

The ability of rainfall to remove arsenic acid residue from the cotton plant after desiccation and prior to ginning tends to greatly reduce potential arsenic emissions from the gin.[5,25,26,27] Laboratory analyses of gin trash indicated that approximately 74 percent of the arsenic content was water extractable.[28] Substantial work done by Miller, C.S., et al. (1975) indicated that there is no relationship between the amount of desiccant applied and the arsenic contents of gin trash. Through a thorough study of 13 gins over the length of a ginning season, no positive relationship was indicated between the quantity of desiccant applied and the amount of arsenic acid residue in the gin trash.[13] The level of arsenic residue in the gin trash was correlated to the amount of rainfall received, growing conditions, and the type harvester used, and not by the total amount of desiccant applied.[5,13]

7.1.3.4 Efficiency of Desiccant Application. The efficiency with which the arsenic acid desiccant is applied to the cotton field directly influences how much arsenic is left on the plants and potentially may be emitted by the ginning process. The primary application technique, ground spraying, has been estimated to be about 5 percent efficient.[29,30] Application efficiency is defined to be the amount of arsenic acid that eventually reaches or contacts plant leaves, stems etc. divided by the amount directed at the plant.

The poor correlations determined in past studies[29], between the total amount of arsenic acid sold and applied as a desiccant to the total amount of arsenic found in the gin trash, can partially be explained by the 5 percent application efficiency estimation. By using the 5 percent application efficiency assumption and the calculations presented in Appendix A-7, the difference between the total arsenic (elemental) quantity actually contacting the plant and the quantity found in the gin trash can be estimated to vary by less than 1 percent. The quantity of material not contacting the plant falls on the soil and can be dispersed in the ambient air as windblown dust. As a result any ambient air sampling for arsenic attributable to cotton gins could be biased high due to windblown dust from the arsenic-contaminated soil in surrounding fields.

7.1.3.5 Translocation and Transformation of Arsenic Acid. Potential inorganic arsenic emissions from a cotton gin (handling arsenic acid-desiccated cotton) may be affected by the translocation of arsenic acid into the main stalk and roots of the plant, and by the transformation of inorganic arsenic acid to organic arsenic compounds. Studies on cotton plants have demonstrated that once arsenic acid is sprayed on the leaves of a plant and absorbed, it can be translocated to other parts of the plant.[28,29] Some parts of the plant, primarily the stalk or main stem, are usually left in the field after stripper harvesting. Arsenic acid which has been translocated into these parts would not find its way to the gin where it could be emitted. Work performed by Miller and Aboul-Ela (1965) indicated that arsenic acid applied to the cotyledonary leaves of a cotton plant moved into the petioles (leaf stem) within one hour and into the main plant stalk within two hours.[28] Once in the main stalk, movement was towards the plant root with no upward movement recorded. The application of arsenic acid to the first foliar leaves of cotton plants resulted in little or no translocation out of the leaf.[28] Further laboratory work by Miller

(1974) indicated that when arsenic acid was applied to the stem of cotton regrowth branches, 71 percent of the arsenic was translocated.[29] However, because no translocation data on commercial field cotton crops have been determined, it is unreasonable to speculate on the extent that translocation may be occurring in desiccated field plants.

Although definitive work has not been done for cotton plants, evidence suggests that some percentage of the arsenic acid absorbed by a cotton plant is converted to organic arsenic compounds. This type of natural transformation has been demonstrated in grass plants. Twelve hours after the application of a solution of sodium arsenite, trimethylarsine was detected in grass samples.[31] The cycle of inorganic arsenic transformation to organic arsenic compounds has been shown to be a natural arsenic detoxification mechanism.[31,32,33] In addition to trimethylarsine, methylarsine, dimethylarsine, and methylarsonic and methylarsinic acids have been observed as a result of natural detoxification. Figure 7-2 shows a simplified version of the natural arsenic transformation cycle in the environment.

No quantification has been made on the rate or extent of the transformation in cotton plants. It is probable that not all of the arsenic content measured in tests of gin trash (Durrenberger, Miller) was inorganic arsenic. Additional sampling and analysis work needs to be done on gin trash samples to speciate between inorganic and organic arsenic.[31,33,34]

### 7.1.4 Inorganic Arsenic Content of Gin Trash

There have been two scientific studies that attempted to estimate the arsenic content of gin trash that was produced from desiccated stripper cotton. The first study by Durrenberger (1974) sampled trash from seven gins and determined that the average arsenic content (as total elemental arsenic) was 2000 ppm or 0.20 percent.[27] The second study by Miller, et al. (1975) measured the arsenic levels in gin trash at 13 gins and found that the arsenic levels (as total arsenic) ranged from 50 to 450 ppm, and averaged about 225 ppm (0.0225 percent).[13] The most recent work in this area by the U.S. EPA and the U.S. Department of Agriculture (USDA) concluded that the Miller, et al. study used more precise analytical detection methods to determine the average arsenic content in gin trash, and therefore was more accurate than Durrenberger.[35] Based on the recommendations made in the EPA-USDA report, 225 ppm was used as the arsenic content of gin trash from desiccated stripper cotton for the analyses in this document.

As stated, the arsenic values for both studies are expressed as total elemental arsenic. No measurements were made on the relative split between inorganic and organic arsenic in the trash. The quantity of inorganic arsenic in the total arsenic measurement may be lowered due to the effects of transformation as discussed in Section 7.1.3.5. Arsenic content results expressed as total arsenic may be biased high by the arsenic contribution of the organic arsenical herbicides DSMA and MSMA which are frequently applied

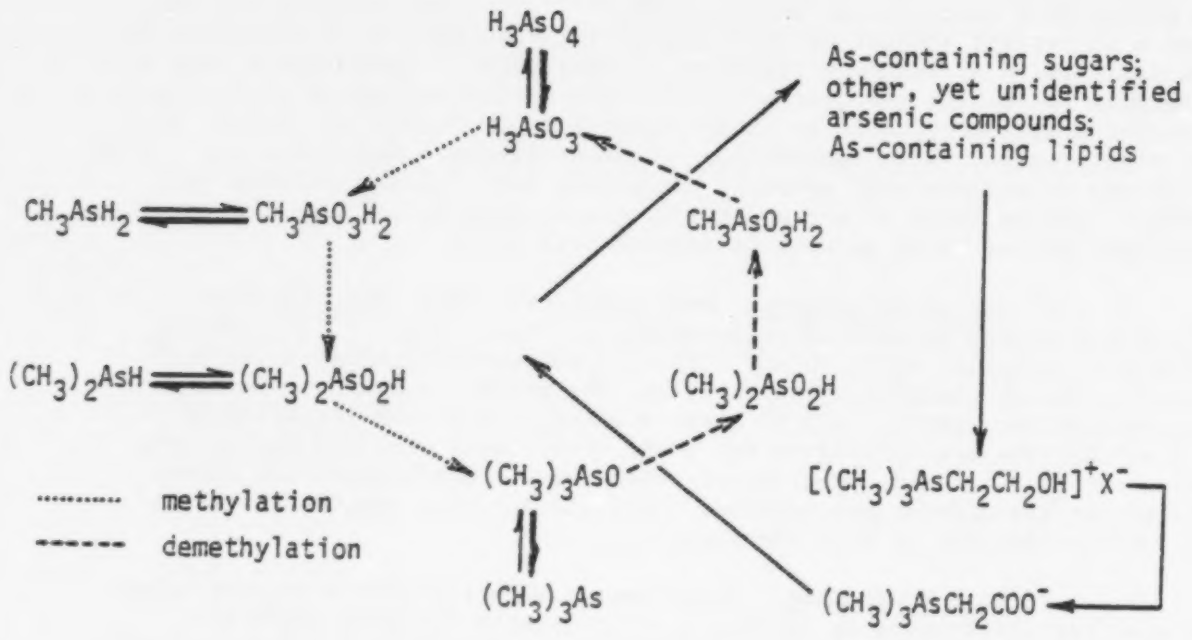

$H_3AsO_4$
$H_3AsO_3$
As-containing sugars; other, yet unidentified arsenic compounds; As-containing lipids
$CH_3AsH_2$
$CH_3AsO_3H_2$
$CH_3AsO_3H_2$
$(CH_3)_2AsH$
$(CH_3)_2AsO_2H$
$(CH_3)_2AsO_2H$
$(CH_3)_3AsO$
$[(CH_3)_3AsCH_2CH_2OH]^+X^-$
methylation
demethylation
$(CH_3)_3As$
$(CH_3)_3AsCH_2COO^-$

Figure 7-2. The transformation cycle of arsenic compounds in the environment.[33]

to cotton. The potential for this type of bias reinforces the need for speciation when arsenic analytical tests are conducted.

### 7.1.5 Alternatives to Arsenic Acid Desiccation

7.1.5.1 Paraquat. Besides arsenic acid, paraquat is the only other desiccant registered for use on cotton. It too, however, is proposed for Rebuttable Presumptions Against Registration (RPAR) by EPA. Paraquat is not as effective a desiccant as arsenic acid.[12,25] In tests between the two, even a 50 percent greater per acre use of paraquat was not as effective in the desiccation of regrowth leaves as arsenic acid.[12] Researchers have also attempted to combine paraquat with other substances (primarily additives or defoliants like endothall) to obtain desiccants equivalent to arsenic acid in effectiveness. This combination, while an adequate desiccant, was not as effective as arsenic acid alone.[25] Endothall has also been blended with arsenic acid in hopes of achieving synergistic desiccation effects, however, the blend did not work as well as arsenic acid alone.

7.1.5.2 Use of Defoliants. Defoliants, wiltants, and regrowth inhibitors cannot be used as replacements for desiccants.[4,5,12] Sodium chlorate, cacodylic acid, Folex® (tributyl phosphorotrithioite) and DEF® (S,S,S-tributyl phosphorotrithidate) are the primary commercial defoliants recommended for cotton. All of these substances with the exception of sodium chlorate are candidates for RPAR. Defoliants will not perform the function of desiccants, particularly when there are second-growth leaves present at the time of application.[5] Defoliation only removes the leaves, it does not dry out or kill the plant.

7.1.5.3 Heat Treatments. Experimental work has been conducted using intense heat treatments to desiccate cotton plants in preparation for stripping. The heat treatments consumed approximately 37.9 liters (10 gal) of liquid propane gas (LPG) per acre treated. Leaf desiccation resulted from 2.5 $J/cm^2$ (2.2 $Btu/ft^2$) of heat.[11] Ideal time-temperature exposure for defoliation response was 850 degree seconds above 54°C (130°F). Presently, no major cotton equipment manufacturers are producing such units.[11]

7.1.5.4 Conclusion on the Alternatives to Arsenic Acid. Presently, there are no chemical replacement or new desiccation techniques that perform with the effectiveness of arsenic acid in preparing short-season cotton for mechanical stripper harvesting.[5,11]

### 7.1.6 Characterization of Cotton Gins Handling Arsenic Acid-Desiccated Cotton

7.1.6.1 Model Cotton Gins. As discussed in Section 7.1.1, about 320 separate cotton gins process arsenic acid-desiccated cotton. It was not possible in this study to determine the process parameters and configuration of every gin that may potentially be emitting inorganic arsenic. As a result, to obtain a reasonable estimate of the inorganic arsenic emissions from the source category, model cotton gins were designed that are representative of the operations and emissions of the gin population.

Four model cotton gins were developed based on the average number of bales of lint cotton that could be produced on an hourly basis. The four model gins produce 4, 7, 12, and 20 bales/hr of product lint cotton. A bale of lint cotton was assumed to weigh 227 kg (500 lb).[36] Table 7-1 presents the production data associated with each model gin. Of the approximately 320 gins handling arsenic acid-desiccated cotton, 10 percent or 32 gins gin 4 bales/hr, 30 percent or 96 gins gin 7 bales/hr, 50 percent or 160 gins gin 12 bales/hr, and 10 percent or 32 gins gin 20 bales/hr.[1,37,38] The model gins were specifically designed to process stripper-harvested cotton that contains an average of 386 kg (850 lb) of trash material per bale of lint cotton produced. A flow diagram of the model gin equipment configuration is given in Figure 7-3.[39,40,41] All four model gins contain the same basic cotton cleaning equipment.

The use of cyclones and particulate filter media for trash emissions control, particularly at gins handling stripper-harvested cotton, is accepted as a necessary and a routine part of gin operation due to the large quantity of particulate matter generated from input seed cotton trash.[9,38] The particulate emissions containing inorganic arsenic from model gin emission points 1 to 5, 9, and 10 (Figure 7-3) are collected by cyclones and are routed to a bur hopper or dust house for storage. Emissions from model gin emission points 6, 7, and 8 are controlled by covering the condenser drums at each of these points with a screen filter media.[6,9,38] The sources of arsenic-containing particulate emissions from the model gin are characterized in the following section (7.1.6.2). A detailed discussion of the model gin particulate emission collection and control equipment is given in Section 7.2.2.

7.1.6.2 Potential Inorganic Arsenic Emission Points in the Cotton Ginning Process. Because of the spraying method used to apply arsenic acid, it appears that the entire cotton plant would be contaminated with arsenic. However, the available data do not support this implication. As discussed in Section 7.1.4, analytical tests conducted on gin trash, lint cotton, and cotton seed from arsenic acid-desiccated cotton demonstrated that gin trash was the predominant source of arsenic.[13] Gin trash consists of leaves, burs, sticks, and hulls. Arsenic was not detected in the majority of tests on lint cotton and cotton seed.[5,27,42,43]

The seed cotton which has been stripper-harvested in the field comes into the gin containing lint cotton, cotton seed, and arsenic-contaminated trash. Process steps at the gin clean and extract trash components from the seed cotton, separate the lint cotton from the cotton seed (ginning), and clean the separated lint cotton. These steps are performed in one of two parts of the gin known as the "high pressure" and "low pressure" sections. The sections are denoted as high and low pressure because of the relative pressure against which each system must operate. For the high pressure

TABLE 7-1. PRODUCTION-RELATED DATA FOR THE COTTON GIN MODEL PLANTS

| Model Gin Number | Model Gin Size (bales lint cotton/hr) | Average Hours of Operation per Season[a] | Average Capacity Utilization[a] | Hourly Throughput of Seed Cotton Mg (tons) |
|---|---|---|---|---|
| 1 | 4 | 400 | 31% | 4.0 (4.4) |
| 2 | 7 | 600 | 48% | 7.0 (7.7) |
| 3 | 12 | 800 | 52% | 12.0 (13.2) |
| 4 | 20 | 800 | 52% | 20.0 (22) |

[a] Reference 37.

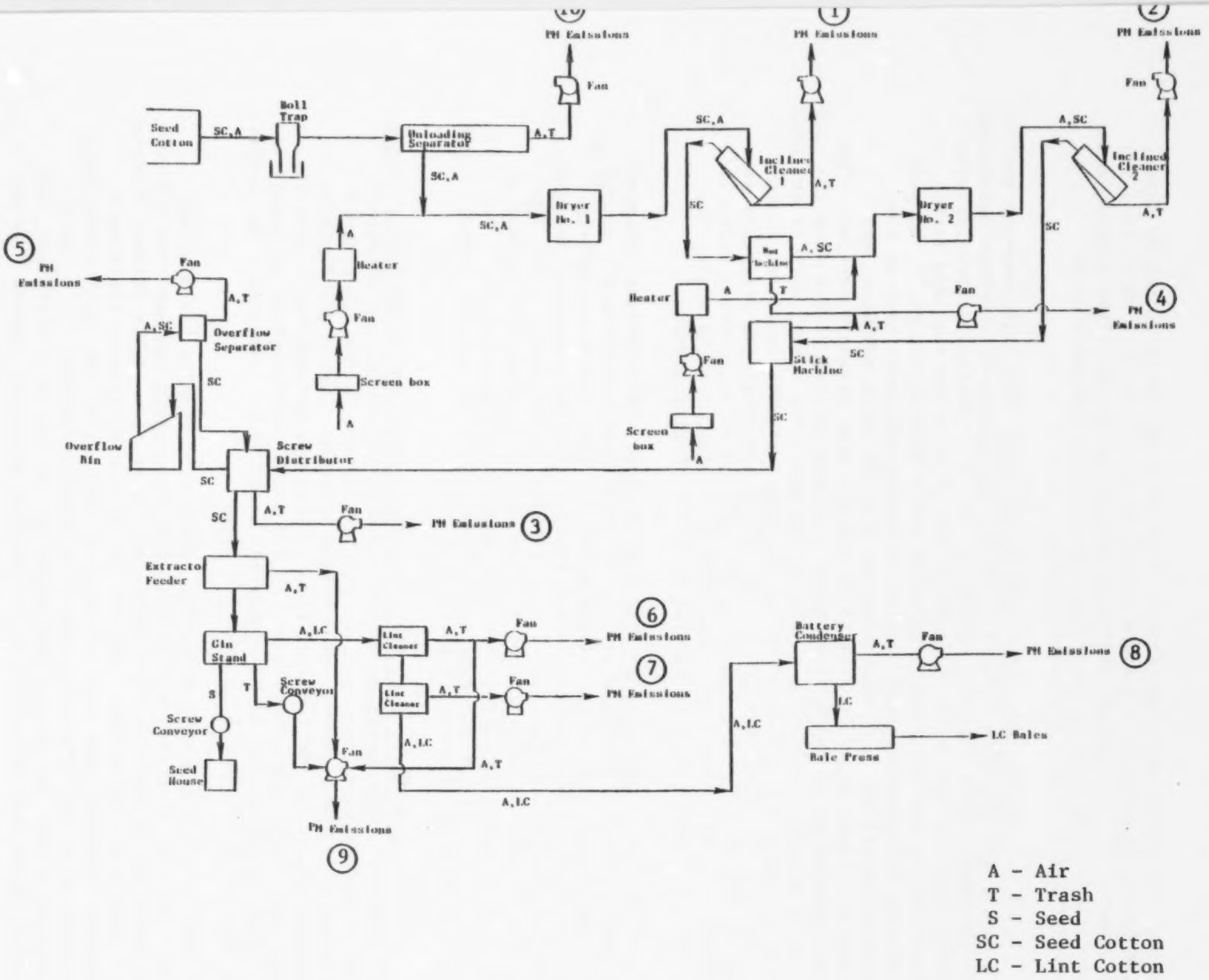

⑩
PM Emissions
Fan
①
PM Emissions
②
PM Emissions
Fan
Seed Cotton
SC, A
Boll Trap
Unloading Separator
A, T
SC, A
SC, A
Inclined Cleaner 1
A, T
SC
Dryer No. 1
SC, A
A
Heater
Fan
Screen box
A
A, SC
Inclined Cleaner 2
A, T
Dryer No. 2
SC
Bur Machine
A, SC
Heater
A
T
Fan
④
PM Emissions
A, T
Stick Machine
SC
Fan
Screen box
A
SC
⑤
PM Emissions
Fan
A, T
A, SC
Overflow Separator
SC
Overflow Bin
Screw Distributor
SC
SC
A, T
Fan
PM Emissions ③
Extractor Feeder
A, T
Gin Stand
A, LC
Lint Cleaner
A, T
Fan
⑥
PM Emissions
Lint Cleaner
A, T
Fan
⑦
PM Emissions
S
T
Screw Conveyor
Screw Conveyor
Seed House
Fan
A, LC
A, T
A, LC
PM Emissions
⑨
A, LC
Battery Condenser
A, T
Fan
PM Emissions ⑧
LC
Bale Press
LC Bales
A - Air
T - Trash
S - Seed
SC - Seed Cotton
LC - Lint Cotton

Figure 7-3. Cotton gin model plant.

section this pressure ranges from 25.4 to 50.8 cm (10 to 20 in) of water, while in the low pressure section pressures of 2.5 to 12.7 cm (1 to 5 in) are common.[44,45] Potential inorganic arsenic emissions (from arsenic acid desiccation) from both the high and low pressure systems will be characterized in the following sections.

7.1.6.2.1 Cotton gin high pressure section. The high pressure section of a cotton gin includes primarily the air discharges or exhausts associated with the seed cotton cleaning equipment.[44,45,46] Basically this includes the gin cleaning equipment in place at the point where the seed cotton enters the gin system through the point where ginning occurs.[45] In gins processing stripper-harvested cotton, cleaning equipment such as the unloading separator, inclined cleaners, bur and stick machines, and extractor feeders would be present in the gin high pressure section. The arsenic-contaminated trash which these cleaning devices remove from the seed cotton is pneumatically exhausted from the gin, thus making each of the seed cotton cleaning stations a potential inorganic arsenic emissions source. The location of these emission points within a typical gin structure are shown in Figure 7-3. The high pressure section of a gin emits burs, leaf and stick pieces, hulls, and large soil particles, and therefore, the majority of arsenic that is emitted from the ginning process.

7.1.6.2.2 Cotton gin low pressure section. The cleaning equipment included in the low pressure section of a gin consists primarily of the first and second lint cotton cleaners and the lint cotton condensers.[44,46] The lint cleaners and condensers are sources of particulate and inorganic arsenic emissions in the form of lint fly and cotton dust.[47] The low pressure system, however, is not a large source of arsenic emissions as evidenced by tests on lint cotton and cotton seed for arsenic.[48] For this reason, control of low pressure section emissions for arsenic removal could be very costly as illustrated in Section 7.3.1.2.

7.1.6.3 Sources of Fugitive Inorganic Arsenic Emissions from a Cotton Gin. Fugitive particulate emissions, potentially containing inorganic arsenic, are emitted from a cotton gin in addition to the gin process emissions from the high and low pressure systems. Cotton gin fugitive emissions may be in the forms of fine-leaf trash, bur material, lint fly, or cotton dust depending on the source. The predominant sources of fugitives are building and piping leaks, equipment leaks (e.g., cyclones), bur hopper dumping, and wind blowing of open bur piles.

The level of fugitive emissions from cotton ginning has not been quantified. No test data are available to accurately estimate the absolute mass emission of fugitive particulate or the relative split between process and fugitive gin emissions. Experts in the cotton ginning field have estimated, however, that approximately 50 percent of the total particulate emissions resulting from a gin are from fugitive sources.[14,49] As the collection system for gin process emissions becomes more efficient, the relative percentage contribution of fugitive emissions becomes greater.

Bur hopper dumping is generally the largest source contributing to gin fugitive emissions.[49] Most gins have the bur hopper elevated such that a truck or trailer can be placed under the hopper doors. The doors can then be opened as needed and the gin trash collected by the cyclones released into the waiting trucks. The emissions from hopper dumping are intermittent and the emission periods short in duration. The dumping of these large quantities of particulate matter (1500 to 7500 kg/hr) into the haul truck or trailer and their subsequent displacement causes fugitive emissions. Any wind during dumping worsens the fugitive emissions problem. The fugitives from the bur hopper dumping operation are mainly trash from the high pressure section of the gin. Even though it has not been measured, the arsenic content of the fugitive emissions is, for the purposes of this study, assumed to be the same as the process emissions, 225 ppm by weight.

Other fugitive emission sources not directly related to the ginning operation may contribute to the ambient concentrations of arsenic found in the atmosphere around a gin. These sources are the mechanical stripper and open cotton fields that have been harvested. When the mechanical strippers are in operation they displace dust that may contain arsenic.[49] Based on the poor application efficiency of the arsenic acid desiccants (Section 7.1.3.4), open, harvested fields could be significant sources of windblown soil containing arsenic.

## 7.2 INORGANIC ARSENIC EMISSIONS OCCURRING UNDER EXISTING REGULATIONS

### 7.2.1 Regulatory Impacts

The only environmental regulations having an impact on inorganic arsenic emissions from cotton gins are State particulate limitations. However, because cotton gins are classified as agricultural sources they are exempted from the general particulate regulations, and are usually given separate, less stringent process weight-based limitations to follow.[50,51,52] Gins in Oklahoma are also regulated under that State's general opacity laws which limit source opacity to 20 percent.[50]

Based on the wording of particulate regulations in both Texas and Oklahoma and the comments of air quality officials in these states, it appears that gin regulation is based primarily on an "equipment standard" and not on some process mass emission rate.[50,51,52] Although both states do periodically inspect gins, they do not perform mass emission tests to determine compliance with the agricultural process weight regulation. Gins in Oklahoma are inspected once a year, while Texas gins are generally only inspected when a public nuisance complaint is received.[50,51]

In terms of an equipment standard, both Texas and Oklahoma attempt to get cotton gins to install various types of collection and control equipment to reduce particulate emissions from high and low pressure gin exhausts. If the gins install the necessary equipment, then the State is basically satisfied that the gin is in compliance.[50,51] For example, in Oklahoma small diameter, high efficiency cyclones are required on the high pressure section emission points and 100 mesh screen covering is required on the condenser drums of low pressure section emission points.[50] The level of existing arsenic emissions is dictated by the performance of these required control devices and not some process weight-based particulate limitation. The cotton gin model plants in Section 7.2.2 were assumed to be equipped with the devices required by Texas and Oklahoma.

Gins are not viewed as serious emission sources of either particulate or arsenic matter by Texas or Oklahoma.[50,51] Neither State pursues gins as violators of the NAAQS for total suspended particulate matter even though measured ambient concentrations around gins is frequently above the primary and secondary standards.[27,50,51,53] The States believe that the agricultural status and seasonality of the gin sources does not warrant consideration under the NAAQS.[49,50]

In the past, arsenic could be emitted from gin sources through the process of burning gin trash for disposal. However, today neither Texas nor Oklahoma allow the burning of gin trash, therefore, this source for arsenic emissions no longer exists.[54]

Occupational exposure regulations issued by OSHA do not affect the control or reduction of inorganic arsenic emissions from cotton gins.[55] The OSHA standard for airborne inorganic arsenic, at 29 CFR 1910.1018 specifically excludes gins because they are classified as agricultural sources. Standards that have been issued for cotton dust, which could indirectly affect arsenic levels, either do not apply to cotton gins (29 CFR 1910.1043) or have been deleted from the books by the courts following suits against OSHA.[55]

The majority of gins handling arsenic acid-desiccated cotton in Texas and Oklahoma are in compliance with all existing regulations as applied and enforced in these States. Therefore, the existing degree of control is equivalent to the baseline.

### 7.2.2 Baseline Inorganic Arsenic Emissions and Controls

The control devices used at a cotton gin to remove arsenic particulate matter from various exhaust streams is the same equipment that is used to remove any other gin trash because any arsenic leaving the gin will be contained on trash material. By controlling gin particulate emissions, arsenic emissions are also controlled. The types of particulate control devices used in a cotton gin are different for high and low pressure section emissions.[45] Different devices are applied because the high pressure section is emitting mostly large trash (burs, sticks, leaves, etc.) potentially containing arsenic, while the low pressure section emits primarily small particle size lint fly and cotton dust.[45] The control devices and emissions characteristic of each gin system will be discussed in the following two sections.

#### 7.2.2.1 High Pressure Section Controls and Inorganic Arsenic Emissions.

The standard collection or control device for gin high pressure section emissions is a cyclone.[38,56,57,58] Cyclones are predominantly used because they are effective, inexpensive, and require little maintenance. The type of cyclone used at cotton gins, which is illustrated in Figure 7-4, was developed by the Atomic Energy Commission (AEC) and is known as a small diameter, high efficiency cyclone or a 2D-2D cyclone.[57] The 2D-2D cyclone is equal to baseline control for the high pressure section emissions.

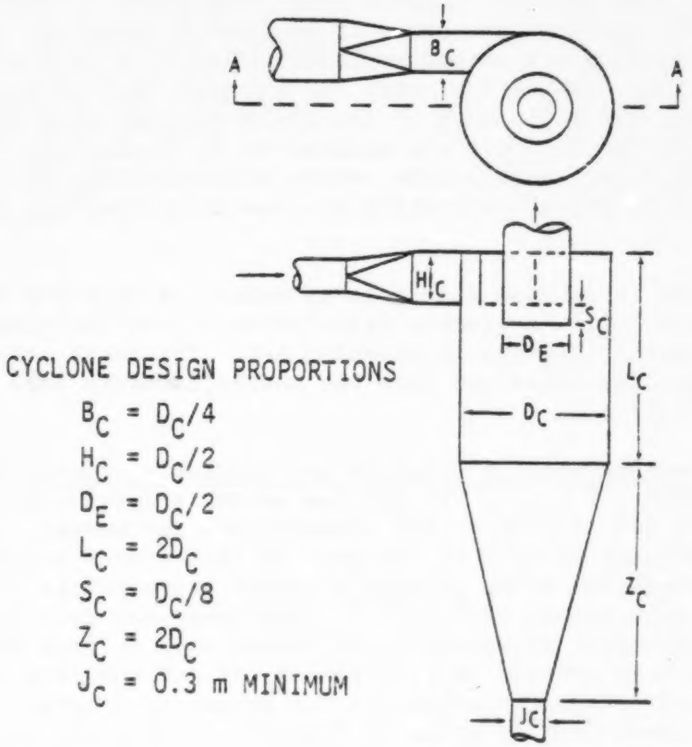
Small diameter, 2D-2D cyclones have been shown to be very efficient on the sizes of particles predominantly found at a cotton gin. Testing by Baker and Stedronsky (1967) indicated that 99.2 percent of stripper cotton trash had a particle size diameter greater than 74 microns.[59] Tests performed on the 2D-2D cyclone have shown it capable of reducing 99.9 percent of all particulate emissions larger than 20 to 30 microns in diameter.[60,61] To allow for the fact that not all gins have properly sized and operated cyclones, the efficiency of the 2D-2D cyclones used on the model cotton gins (Section 7.1.6.1) was assumed to be 99 percent. The 2D-2D cyclones are used to collect particulate matter exhausted from emission points 1-5, 9, and 10 in Figure 7-3, which are basically the high pressure emission points.

The baseline arsenic process emissions as estimated from the model gins are presented in Table 7-2. An example calculation of how the process emissions were calculated is given in Appendix A-7. The total arsenic (as elemental arsenic) process emissions from the source category were estimated to be 1.6 Mg (1.8 tons)/yr.

#### 7.2.2.2 Low Pressure Section Controls and Inorganic Arsenic Emissions.

As discussed in Section 7.1.6.2.2, the gin low pressure section emissions come from the primary and secondary lint cleaners and the battery lint condenser. Eighty percent or more of the gins in this source category use coverings over the condenser drums at each of these three points to reduce lint fly and cotton dust emissions.[6,9,38,62] The condenser drum coverings consist of either fine-mesh, stainless-steel screen wire or fine perforated metal. As the air stream containing lint passes through the drum coverings the lint is caught and eventually collected. A schematic diagram of a typical covered condenser drum is given in Figure 7-5. For the lint fly type particulate matter being emitted in this section at the gin, covered condenser drums are about 40 percent efficient.[38]

The other 20 percent of gins use in-line filters to control low pressure system particulate emissions, however, the use of in-line filters is declining.[9,38,63] The three most prevalent types of in-line filters are depicted in Figure 7-6. Tests performed by the U. S. Department of Agriculture (USDA) indicated that the filter types are equally efficient. The average collection efficiency for an in-line filter was determined to be approximately 81 percent.[64]



A
A
$B_C$
$H_C$
$S_C$
$D_E$
$D_C$
$L_C$
$Z_C$
$J_C$

CYCLONE DESIGN PROPORTIONS

$B_C = D_C/4$

$H_C = D_C/2$

$D_E = D_C/2$

$L_C = 2D_C$

$S_C = D_C/8$

$Z_C = 2D_C$

$J_C$ = 0.3 m MINIMUM

Figure 7-4. Relative dimensions for a 2D-2D, small diameter design cyclone.

## TABLE 7-2. BASELINE ARSENIC EMISSIONS FROM COTTON GIN MODEL PLANTS[a]

| | | PROCESS EMISSIONS | | | | FUGITIVE EMISSIONS | |
|---|---|---|---|---|---|---|---|
| | | High Pressure Section | | Low Pressure Section | | | |
| Model Gin Size (bales lint/hr) | Number of Gins In the Population | Single Plants kg(lb)/hr | All Plants kg(lb)/yr | Single Plants kg(lb)/hr | All Plants kg(lb)/yr | Single Plants kg(lb)/hr | All Plants kg(lb)/yr |
| 4 | 32 | 0.0025 (0.0056) | 32.5 (71.7) | 0.000018 (0.00004) | 0.22 (0.49) | 0.0025 (0.0056) | 32.5 (71.7) |
| 7 | 96 | 0.0045 (0.0099) | 259 (570) | 0.00003 (0.00007) | 1.76 (3.88) | 0.0045 (0.0099) | 259 (570) |
| 12 | 160 | 0.0077 (0.0169) | 981 (2163) | 0.00005 (0.00012) | 6.71 (14.8) | 0.0077 (0.0169) | 981 (2163) |
| 20 | 32 | 0.0128 (0.0282) | 327 (722) | 0.00009 (0.00019) | 2.24 (4.93) | 0.0128 (0.0282) | 327 (722) |

[a] Arsenic emissions are expressed as total elemental arsenic.

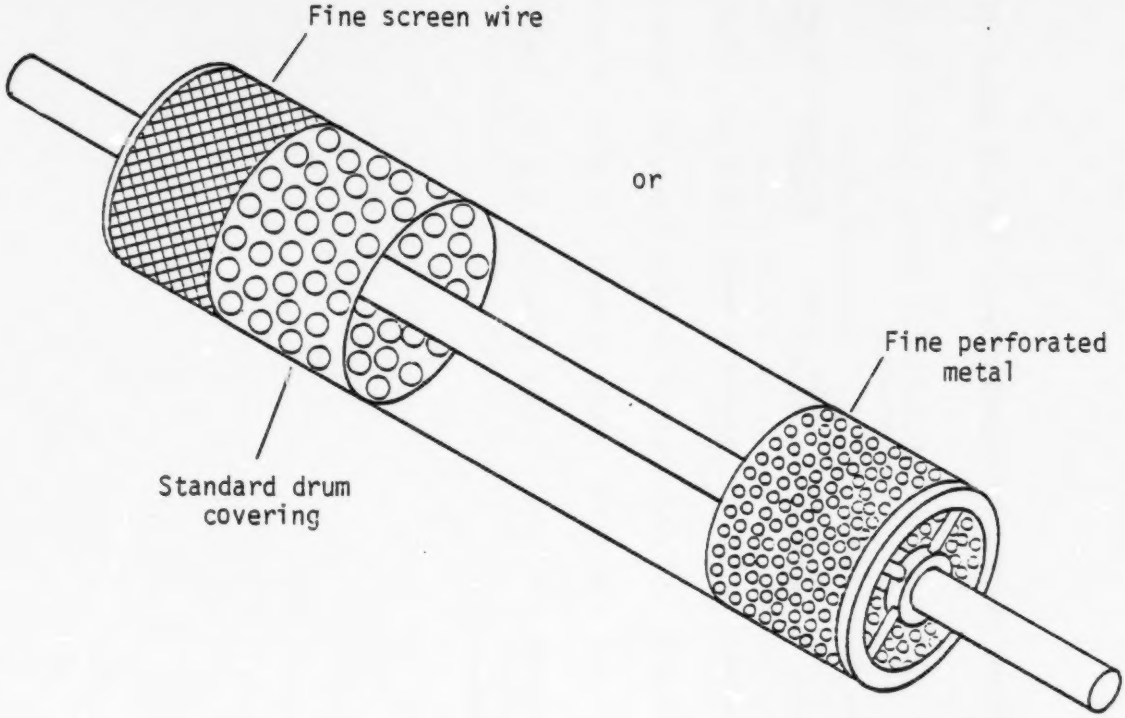
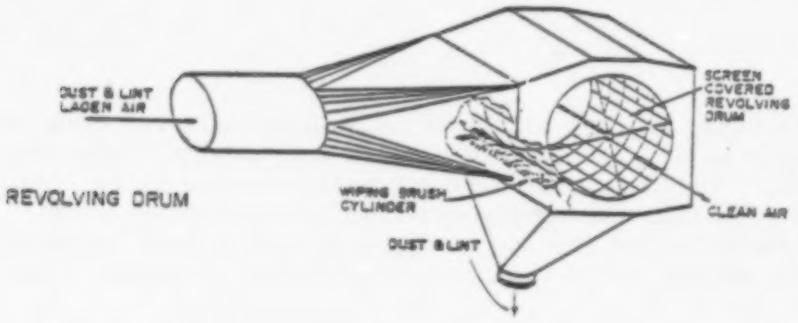
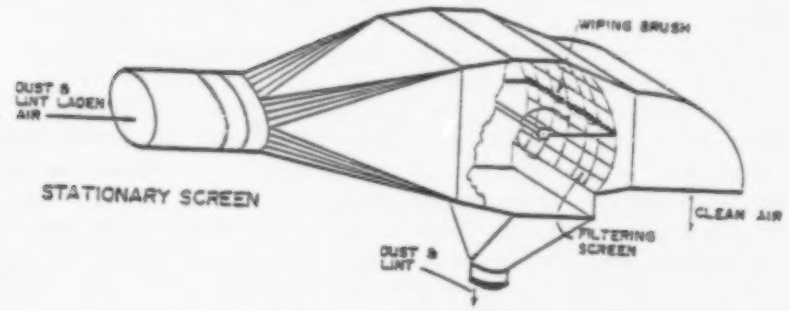

Fine screen wire
or
Fine perforated metal
Standard drum covering

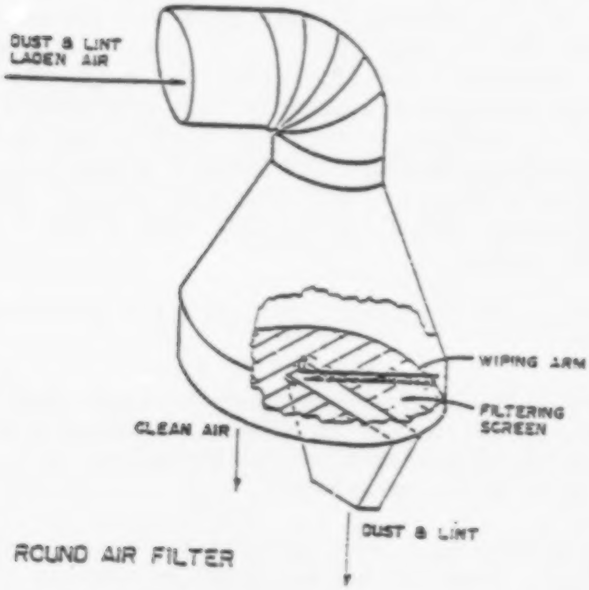
Figure 7-5. Condenser drum with screen wire and fine perforated metal coverings.[62]


DUST & LINT LADEN AIR
SCREEN COVERED REVOLVING DRUM
REVOLVING DRUM
WIPING BRUSH CYLINDER
CLEAN AIR
DUST & LINT

a. Revolving drum in-line filter


WIPING BRUSH
DUST & LINT LADEN AIR
STATIONARY SCREEN
CLEAN AIR
FILTERING SCREEN
DUST & LINT

b. Stationary screen in-line filter


DUST & LINT LADEN AIR
WIPING ARM
FILTERING SCREEN
CLEAN AIR
DUST & LINT
ROUND AIR FILTER

c. Horizontal, round in-line filter

Figure 7-6. Schematic diagrams of the most prevalent in-line filters.[64]

Despite being half as efficient as in-line filters, covered condenser drums are used more predominantly because they are less expensive to install and maintain. The installation of a typical in-line filter costs about seven times more than the simple covering of a condenser drum.[62] Because of its predominance in the ginning industry the model gins presented in this document are assumed to be equipped with covered condenser drums as baseline control.

It is difficult to assess the level of arsenic emissions from the low pressure section of the gin because tests on these lint fly and cotton dust particulates indicated that virtually no or almost undetectable amounts of arsenic were present (Sections 7.1.6.2.1 and 7.1.6.2.2). However, for the purposes of this study the arsenic level (total elemental arsenic) of the low pressure section emissions is assumed to be 1.33 ppm by weight of the total particulate matter emitted. The 1.33 ppm value was selected as the arsenic level because it represents the highest amount of arsenic measured in cotton seed samples.[5] Therefore, it can serve as an upper bound for the arsenic emissions estimate. Arsenic emissions from the low pressure section of the model gins are presented in Figure 7-2. An example calculation for estimating low pressure section arsenic emissions is given in Appendix A-7. Annual arsenic emissions from the low pressure sections of the total source category are estimated to be 10.9 kg (24.1 lb).

7.2.2.3 Cotton Gin Model Plant Fugitive Inorganic Arsenic Emissions. As summarized in Section 7.1.6.3, fugitive arsenic emissions from cotton gins handling arsenic acid-desiccated cotton are estimated to be equal to process arsenic emissions from the gin.[49] Table 7-2 presents the estimated fugitive arsenic emissions for all cotton gin model plants. Only gin high pressure emissions are included because they constitute the emissions that are collected by cyclones, sent to a bur hopper, and potentially emitted as fugitives during hopper dumping. Bur hopper dumping is important because it is the largest single source of gin fugitive arsenic emissions.[49] Other sources of gin fugitive emissions include open trash piles and leaks from gin equipment and piping.

Several techniques to control fugitive gin emissions are available including:

- the use of mechanical conveyors to move trash into the bur hopper,
- the use of enclosures at hopper unloading areas,
- the use of windscreens around bur piles, and
- the use of wet suppression.

All of these techniques have been applied at various gins with varying degrees of success. However, the majority of the gin population either does not use these techniques or does not properly apply them when used.[49] Cotton specialists report that the use of mechanical conveyors is just beginning to gain popularity in the ginning field due to efforts to reduce fan usage and electricity consumption. Conveyor usage is not widespread.

The use of enclosed hopper unloading areas has not been greatly successful because ginners have indicated that the haul truck engines become so clogged with particulate material that they fail to operate. As a result, ginners open the doors to the enclosure during dumping or they poorly maintain the structure such that leaks are allowed to develop and fugitive emissions once again occur. The majority of ginners do not use wet suppression because it disrupts the operation of the equipment used to spread the gin wastes on the fields. When the gin trash gets wet, the spreading equipment can become clogged and malfunction. However, if the gin wastes are to be mass-dumped on the fields, then wet suppression causes no problems.[49] Despite the difficulties that have been incurred in attempting to control cotton gin fugitive emissions, several facilities have successfully applied the techniques discussed above, particularly the use of mechanical trash conveying and bur hopper enclosures.[49]

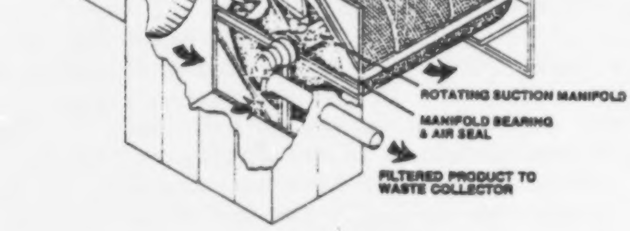
The type and extent of fugitive emission control required cannot be determined without an examination of each individual cotton gin handling arsenic acid-desiccated cotton. For this reason it is not possible, in a screening study of this type, to recommend an EBC system or an EBC level that could realistically be applied to every gin in this source category. The lack of accurate definition of the amount of inorganic arsenic contained in the fugitive emissions also raises questions as to the need for an EBC level for the purpose of inorganic arsenic control. Because of these many unknown and unquantified variables concerning cotton gin fugitive arsenic emissions, only estimated existing fugitive arsenic emissions will be addressed in this study for the purposes of the population exposure assessment in Section 7.5.

## 7.3 DEFINITION OF EBC OPTIONS

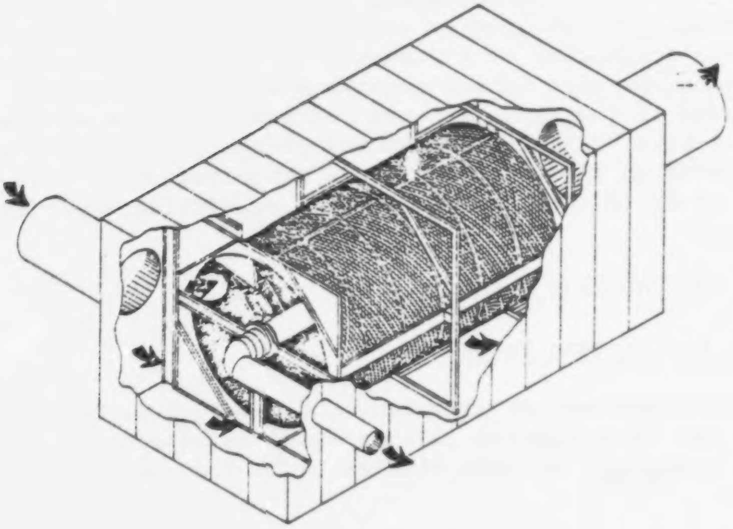
### 7.3.1 EBC Options for Process Emissions

Classical particulate matter emission controls such as fabric filters and scrubbers were not investigated in this study as arsenic EBC options because they have been shown in past studies to be too costly for gin particulate control.[1,65,66]

Because gins are not stringently regulated in Texas and Oklahoma, a situation has developed in which there is little or no incentive for ginners to install highly effective particulate control devices beyond the basic required cyclone and filter setup. As a result, it is difficult to determine potential EBC by examining existing gins in these two States. However, an examination of States such as California and Arizona, where cotton gin regulation and enforcement is stricter, yielded two particulate control systems that were considered for EBC.[26,67] The first device, depicted in Figure 7-7, is known as an Intr-A-Vac.® The Intr-A-Vac® is intended to remove lint and dust particles from cotton gin and textile plant exhaust air streams. It is not a bulk trash handling device, and therefore, must be preceeded by a cyclone bank or separator chamber if it is to be used


CLEAN AIR FILTERS THROUGH SIDES OF FILTERING SECTIONS
CONTAMINATED AIR INLET
SUCTION NOZZLE
ROTATING SUCTION MANIFOLD
MANIFOLD BEARING & AIR SEAL
FILTERED PRODUCT TO WASTE COLLECTOR

WITH ENTRANCE ENCLOSURE



WITH FULL ENCLOSURE

Figure 7-7. Intr-A-Vac® particulate matter control system.[68]

on high pressure exhausts. As shown in Figure 7-7, dust-laden air enters the device and is passed through a stationary screen drum lined with a fur-like filter media. As the air is passed through the filter media the dust particles are caught and eventually vacuumed away by a rotating suction nozzle. The cleaned air is then exhausted to the atmosphere or redirected to other areas.[71]

The second control device for cotton gin EBC consideration is a new type of cyclone known as the "1D-3D" or "long-cone" cyclone, which is illustrated in Figure 7-8. The long-cone cyclone has been demonstrated to be much more efficient than the older 2D-2D or AEC type cyclones, particularly on low pressure system trash.[6,43,69,70,71,72] The long-cone cyclones have been demonstrated to be capable of achieving an average particulate removal efficiency of 94 percent on low pressure exhausts.[43,71,72]

The long-cone cyclones were chosen over the Intr-A-Vac® system for further consideration as an EBC option for process emissions because the particulate removal performance efficiency of the Intr-A-Vac® system has not been demonstrated by any type of testing, and Intr-A-Vac® systems have been used primarily on gins handling relatively cleaner picked cotton and not on the dirtier, stripped cotton of Texas and Oklahoma. In addition, according to local cotton specialists the use of new types of cyclones is more likely to be accepted by ginners than a change to a totally new, unproven system such as the Intr-A-Vac®. The use of long-cone cyclones as an EBC option for high and low pressure system exhausts is discussed in the following two sections.

7.3.1.1 High Pressure Section Exhausts. As discussed in Section 7.1.6.1, the majority of cotton gins in this source category have cyclones in place for high pressure particulate emissions control as a routine part of gin equipment. These primary control cyclones would remain in place under the EBC option. Therefore, under this baseline control condition long-cone cyclones would function as secondary control devices for high pressure section emissions. Long-cone cyclones cannot be installed as the primary control device on most of the high pressure exhausts due to the small diameter design of the cyclone's inlet duct.[73] The large size trash emitted from the high pressure points can clog the small inlet duct and disrupt airflow and performance of the cyclone. However, long-cone cyclones can be installed as the primary cyclone on the suction unloading fan exhaust of the high pressure section because the trash is not large enough to clog the inlet.[73] As an EBC option in this study, long-cone cyclones were used as secondary collection devices on all high pressure section exhausts.

As a particulate and arsenic control device, the long-cone cyclones are used to collect particles from the exhaust stream of the existing 2D-2D cyclone bank. Ninety-nine percent of the exhaust from the baseline 2D-2D cyclones is less than 20 microns in size and is controlled at a 50 percent efficiency by the long-cone system.[69,72,73] The estimated levels of arsenic

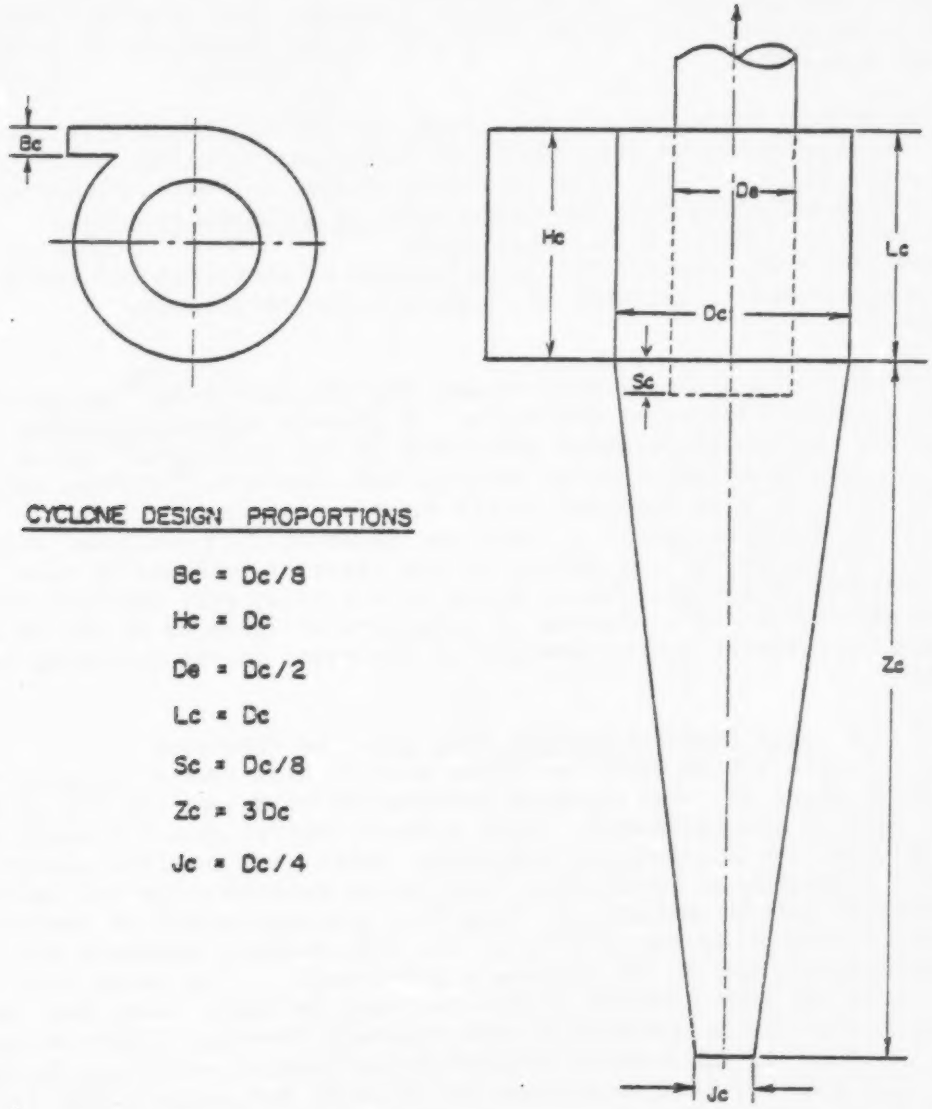

Bc
He
De
Lc
Dc
Sc
Zc
Jc
CYCLONE DESIGN PROPORTIONS
Bc = Dc/8
Hc = Dc
De = Dc/2
Lc = Dc
Sc = Dc/8
Zc = 3 Dc
Jc = Dc/4

Figure 7-8. Relative dimensions of the long-cone cyclone.[70]

emissions resulting from the implementation of the long-cone EBC option are presented in Table 7-3. The total arsenic emissions reduction for the source category, after the implementation of EBC, is estimated to be 804 kg (1800 lb)/year.

7.3.1.2 Low Pressure Section Exhausts. As an EBC option in the low pressure section of the gin, long-cone cyclones function as the primary exhaust cleaning device. The lint fly and cotton dust emissions to be removed will not clog the inlet duct of the long-cone cyclone, therefore, no problems are incurred using the long-cone system as a primary device. Studies performed by the USDA have demonstrated that long-cone cyclones are an average of 94 percent efficient as the primary control device for low pressure section particulate emissions.[45,71] Even though the long-cone devices are technically feasible and effective at controlling these particulate emissions, they are costly. Analytical tests on cotton lint have not found arsenic to be present, thus implying that lint fly emissions would also be devoid of arsenic.

Even if it is assumed that the low pressure section arsenic emissions are equal to these given in Table 7-2, arsenic EBC options may not be justified because of the high arsenic removal cost incurred. To illustrate the cost of arsenic control, the low pressure emissions of the 20 bale/hr model gin will be analyzed. The 20 bale/hr model was selected for analysis because it represents the model plant most likely to be able to afford controls due to the effects of economies of scale. The control cost of long-cone cyclones on low pressure exhausts would be about $48,500/kg ($23,000/lb) or $48.5 million/Mg ($46 million/ton) of arsenic removed from the air. This cost estimate only includes the annualized capital equipment cost, and no other annualized costs such as maintenance and labor, utilities, taxes, and insurance. The equipment cost data used to calculate the arsenic control cost are given in Appendix B-7. Potential arsenic emissions from gin low pressure exhausts will not be discussed further because no inexpensive EBC option appears available.

### 7.3.2 EBC Option for Fugitive Emissions

As discussed in Section 7.2.2.3, no EBC option could accurately be defined and quantified for fugitive inorganic arsenic emissions from cotton gins. EBC was not quantifiable because neither fugitive particulate nor fugitive arsenic emissions from gins have been measured. The level of fugitive arsenic emissions from a particular gin is highly dependent on the gin's own maintenance practices. An across-the-board EBC option may not be applicable to all fugitive emission situations at all gins. The fugitive emission control techniques of bur hopper enclosures, wet suppression, mechanical conveying, and windscreens are useful in reducing fugitives, however, the effectiveness of the techniques in reducing inorganic arsenic emissions has not been quantified. Because of the lack of adequate fugitive emissions data and the variability of the fugitives problem from gin-to-gin, no EBC option for fugitive emissions could be determined. The arsenic

## TABLE 7-3. ARSENIC EMISSION REDUCTIONS ATTRIBUTABLE TO EBC OPTIONS[a]

| Model Plant Size (bales lint/hr) | Baseline Controls | Baseline Arsenic Emissions[b] kg/hr | (lb/hr) | EBC Options | EBC Arsenic Emissions kg/hr | (lb/hr) | Incremental Reduction Over Baseline kg/hr | (lb/hr) |
|---|---|---|---|---|---|---|---|---|
| 4 | 2D-2D Cyclones | 0.0025 | (0.0056) | Long-cone Cyclones | 0.0013 | (0.0028) | 0.0013 | (0.0028) |
| 7 | 2D-2D Cyclones | 0.0045 | (0.0099) | Long-cone Cyclones | 0.0023 | (0.0050) | 0.0023 | (0.0050) |
| 12 | 2D-2D Cyclones | 0.0077 | (0.0169) | Long-cone Cyclones | 0.0039 | (0.0085) | 0.0039 | (0.0085) |
| 20 | 2D-2D Cyclones | 0.0128 | (0.0282) | Long-cone Cyclones | 0.0064 | (0.0141) | 0.0064 | (0.0141) |

[a] Only high pressure section exhausts are presented.

[b] Emissions are expressed as total elemental arsenic.

emissions from area fugitives, presented in Table 7-2, are assumed to remain unchanged for baseline and EBC conditions.

## 7.4 DETERMINATION OF THE INCREMENTAL IMPACTS OF THE EBC OPTIONS

Only the impacts of the EBC options for gin high pressure section arsenic emissions will be presented because, as discussed in Section 7.3.2, low pressure section arsenic emissions are virtually nonexistent or so low that EBC is costly for most ginners. The application of EBC to cotton gins involves the addition of a control device and not the substitution of one control for another. Therefore, the incremental impacts of the EBC option are equal to the actual impacts of the added device.

### 7.4.1 Environmental Impacts

The application of EBC to the model cotton gins results in an increase in the total solid waste load of the gin. The quantity of solid waste is increased because the EBC options collect additional gin trash from the exhaust stream of the baseline controls. The increase in the overall solid waste collected from total gin, either as total particulate matter or arsenic, is shown in Table 7-4. The collected solid waste is generally stored for as long as necessary, and then is put back on the crop fields and incorporated into the soil as a compost material for soil enrichment.[5,74] The trash solid waste can be returned to the soil because it is not hazardous under the Resource Conservation and Recovery Act statutes.[75]

No wastewater or other environmental impacts are produced with the use of the long-cone cyclone EBC option.

### 7.4.2 Energy Impacts

The use of EBC results in increased electrical energy requirements to operate the fan motors of the long-cone cyclone system. Additional fans are required with the long-cone cyclones to overcome the added pressure drop they cause. The incremental energy impact of EBC is represented by the absolute energy impact of the EBC system and is shown in Table 7-5.

### 7.4.3 Control Costs Impacts

This section presents the capital and annualized costs associated with the application of the long-cone cyclone EBC option to the cotton gin model plants. The actual costs of EBC represent the incremental cost that would be incurred by a ginner with the application of the designated long-cone cyclone EBC system. The capital and annualized costs of EBC are given in Table 7-6. The bases for the costs in Table 7-6 are given in Appendix B-7.

### 7.4.4 Economic Impact Resulting from EBC

An economic impact analysis was conducted for the cotton ginning model plants to estimate the potential impact of requiring EBC. Using the cost

TABLE 7-4. SOLID WASTE IMPACTS FROM COTTON GIN MODEL PLANT CONTROL

| Model Plant Size (bales lint cotton/hr) | Incremental Solid Waste Load from EBC Option, Mg(ton)/yr | |
|---|---|---|
| | Arsenic Contained in Solid Waste[a] | Total Solid Waste |
| 4 | neg.[b] | 0.9 (1) |
| 7 | neg.[b] | 2.7 (3) |
| 12 | neg.[b] | 7.3 (8) |
| 20 | neg.[b] | 11.8 (13) |

[a] Expressed as total elemental arsenic.

[b] Negligible incremental difference with the number of significant figures used.

## TABLE 7-5. ENERGY IMPACTS FROM COTTON GIN MODEL PLANT CONTROL

| Model Gin Size (bales lint cotton/hr) | Incremental Consumption for EBC Option, Gj(kWh)/yr |
|---|---|
| 4 | 24.8 (6,900) |
| 7 | 68.4 (19,000) |
| 12 | 166 (46,100) |
| 20 | 260.0 (72,400) |

## TABLE 7-6. CAPITAL AND ANNUALIZED COSTS OF COTTON GIN MODEL PLANT EBC OPTIONS

| Model Gin Size (bales lint cotton/hr) | EBC Equipment | Incremental Arsenic Reduction Attributable to EBC kg/hr | (lb/hr) | Total Capital Cost of EBC[b] | Total Annualized Cost of EBC[a,b] |
|---|---|---|---|---|---|
| 4 | Long-cone Cyclones | 0.0013 | (0.0028) | 23,000 | 4,900 |
| 7 | Long-cone Cyclones | 0.0023 | (0.0050) | 34,500 | 7,800 |
| 12 | Long-cone Cyclones | 0.0039 | (0.0085) | 60,900 | 14,200 |
| 20 | Long-cone Cyclones | 0.0064 | (0.0141) | 81,100 | 19,400 |

[a] The total annualized cost of EBC also equals the incremental cost of EBC.

[b] All costs are in last quarter 1981 dollars.

data in Table 7-6 and the methodology given in Appendix C, revenue and product price increases, required by gins to maintain the same net present values before and after the installation of EBC, were estimated.

The annual revenue increases required by the four model cotton gins range from $3,800 per year in the smallest model plant up to $15,900 in the largest model plant. These increases translate into price increases that range from less than 1¢ per kg (0.45¢ per lb) of baled cotton in the largest model up to 3.5¢ per kg (1.6¢ per lb) in the smallest model. These increases are equivalent to 0.5 percent and 2.1 percent product price increases, respectively. Table 7-7 presents a summary of the revenue and price increases for the cotton gin model plants.

To test the sensitivity of the economic impact results to the various input data, a sensitivity analysis was conducted for the cotton ginning model plants, assuming simultaneous 15 percent decreases in baseline price and annual output and a 15 percent increase in the weighted cost of capital.

The altered assumptions of the sensitivity analysis caused product price increases to rise to 1.1¢ per kg (0.5¢ per lb) of baled cotton in the largest model plant up to 4.4¢ per kg (2¢ per lb) in the smallest model plant. These increases are equivalent to 0.8 percent and 3.0 percent product price increases, respectively. The revenue and price impact sensitivity analysis for cotton gin model plants is summarized in Table 7-8.

### 7.5 POPULATION EXPOSURE DATA

The data in Tables 7-9 and 7-10 were developed during this study for use in an air pollution dispersion model to estimate the population exposure to arsenic from cotton ginning operations. The Strategies and Air Standards Division (SASD) of EPA is using these data in an ongoing effort to estimate exposure to arsenic from this source category.

### 7.6 EASE OF STANDARDS DEVELOPMENT

Technically there are no impediments to applying the long-cone cyclone EBC option to control arsenic emissions from either new or old ginning facilities. The long-cone cyclone technology has been demonstrated and would be applicable to the emissions of any gin in this source category. Ginners would not have a problem obtaining the long-cone cyclones because they are manufactured by several companies that are located in the cotton belt States. In addition, the cyclone design was originated by engineers at Texas A&M University, such that information on the system is readily available.

An important factor to consider before attempting to regulate inorganic arsenic emissions from cotton gins is whether all of the arsenic that is emitted is in the inorganic form. As discussed in Section 7.1.3.6, organic arsenic, which is not listed as a hazardous air pollutant, may be present in

TABLE 7-7. REVENUE AND PRICE IMPACTS FOR COTTON GINS TO ACHIEVE EBC

| MODEL PLANT | REQUIRED REVENUE INCREASE (dollars) | REQUIRED UNIT PRICE INCREASE (dollars per kg) | REQUIRED PERCENT UNIT PRICE INCREASE |
|---|---|---|---|
| 1 | 3,804 | .035 | 2.1 |
| 2 | 6,214 | .014 | 0.8 |
| 3 | 12,117 | .011 | 0.7 |
| 4 | 15,898 | .009 | 0.5 |

TABLE 7-8. SENSITIVITY ANALYSIS OF THE REVENUE AND PRICE IMPACTS FOR COTTON GINS

| MODEL PLANT | REQUIRED REVENUE INCREASE (dollars) | REQUIRED UNIT PRICE INCREASE (dollars per kg) | REQUIRED PERCENT UNIT PRICE INCREASE |
|---|---|---|---|
| 1 | 4,027 | .044 | 3.0 |
| 2 | 6,574 | .018 | 1.2 |
| 3 | 13,954 | .015 | 1.0 |
| 4 | 16,837 | .011 | 0.8 |

TABLE 7-9. COTTON GIN MODEL PLANTS' ARSENIC EMISSIONS DATA

| Model Gin Size (bales/hr) | Emission Points | Baseline Arsenic Emissions, kg/hr | (lb/hr) | EBC Arsenic Emissions kg/hr | (lb/hr) |
|---|---|---|---|---|---|
| 4 | Process | 0.0025 | (0.0056) | 0.0013 | (0.0028) |
| | Area Fugitives | 0.0025 | (0.0056) | 0.0025 | (0.0056)[a] |
| 7 | Process | 0.0045 | (0.0099) | 0.0023 | (0.0050) |
| | Area Fugitives | 0.0045 | (0.0099) | 0.0045 | (0.0099)[a] |
| 12 | Process | 0.0077 | (0.0169) | 0.0039 | (0.0085) |
| | Area Fugitives | 0.0077 | (0.0169) | 0.0077 | (0.0169)[a] |
| 20 | Process | 0.0128 | (0.0282) | 0.0064 | (0.0141) |
| | Area Fugitives | 0.0128 | (0.0282) | 0.0128 | (0.0282)[a] |

[a] No EBC for fugitives could be defined. Fugitive emissions are equivalent in the baseline and EBC cases.

## TABLE 7-10. COTTON GIN MODEL PLANTS' STACK PARAMETERS

| Model Gin Size (bales/hr) | Emission Points | STACK PARAMETERS | | | | |
|---|---|---|---|---|---|---|
| | | Height m (ft) | Diameter m (ft) | Exit Temp. °K (°F) | Flow Rate $m^3$/sec (acfm) | Flow Velocity m/sec (fps) |
| 4 | Process | 8.5 (28) | 0.30 (1.0) | Ambient | 6.4 (13,500) | 20.4 (67) |
| | Area Fugitives | 4.6 (15) | [a] | Ambient | [a] | [a] |
| 7 | Process | 8.9 (29) | 0.37 (1.2) | Ambient | 11.7 (24,750) | 20.4 (67) |
| | Area Fugitives | 4.6 (15) | [a] | Ambient | [a] | [a] |
| 12 | Process | 8.9 (29) | 0.37 (1.2) | Ambient | 21.2 (45,000) | 20.4 (67) |
| | Area Fugitives | 4.6 (15) | [a] | Ambient | [a] | [a] |
| 20 | Process | 9.5 (31) | 0.43 (1.4) | Ambient | 33.4 (70,650) | 20.4 (67) |
| | Area Fugitives | 4.6 (15) | [a] | Ambient | [a] | [a] |

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[a] These parameters are not applicable for the area fugitive source. The area fugitives result when the trash contents of the bur hopper are dumped into a truck and are dispersed by wind. The point of dumping is approximately 4.6 m (15 ft) high. The fugitive emissions that are released are at ambient temperature. The hoppers at the 4 and 7 bale/hr gins are approximately 6.1 m (20 ft) long and 2.0 m (6.7 ft) wide, while the 12 and 20 bale/hr gins have hoppers 9.1 m (30 ft) long and 3.0 m (10 ft) wide.

the emissions to the atmosphere. Studies need to be performed to speciate the arsenic contained in cotton gin emissions in order to assess the severity of the inorganic arsenic problem, since inorganic arsenic is the determined hazardous air pollutant. No speciation for arsenic has been performed on emissions from gins handling arsenic acid-desiccated cotton. However, EPA is preparing to reanalyze the hi-vol filter samples taken during the Durrenburger tests of 1974 (Section 7.1.4) to speciate the arsenic contents. The results of this analytical work should be available from the Environmental Monitoring Systems Laboratory (EMSL) of EPA, Research Triangle Park, North Carolina by mid-1982. To justify the development of emissions standards for inorganic arsenic from cotton gins, the level of inorganic arsenic in gin particulate matter emissions must be quantified.

An entire approach to source testing cotton gins for arsenic emissions and arsenic removal efficiencies for both process and fugitive sources needs to be developed and verified if a decision is made to study cotton gin arsenic emissions. The sampling of gins for arsenic may present problems due to the following:

- difficulty in determining the amount of arsenic coming into the ginning process,
- difficulty in measuring inlet streams to the cyclones by conventional methods due to the large particle sizes of the trash,[76]
- non-existence of test data on fugitive arsenic emissions from gins,
- no testing protocols for gin fugitive emissions have been demonstrated.

Another factor to be considered in any decision to further investigate cotton gins for inorganic arsenic standards development is the view held by the States involved towards gin sources. Neither Texas nor Oklahoma view cotton gins as major emission sources of inorganic arsenic. As a result neither State attempts to directly regulate or monitor potential arsenic emissions from cotton gins. Although the States do indirectly control potential arsenic emissions by means of particulate matter regulations, the level of control achieved is not definable because the particulate regulations are not rigidly enforced. Source testing for compliance determination purposes is not performed in either State. Primarily, Texas and Oklahoma attempt to get gins to install designated control devices, such as cyclones and filters, to reduce the gross particulate emissions problem to a tolerable limit. In the absence of public nuisance complaints, the gin sources are left alone.

Neither Texas nor Oklahoma pursue cotton gins as violators of the NAAQS for particulate even though several measurements around gins have shown gross exceedences of the standards. State officials indicate that because of the many other sources of windblown particulate in these areas, it is not possible to place a blame or a percentage of blame on gins for causing the

NAAQS exceedence. Agricultural fields other than cotton are contributors in these areas. As with the particulate SIP's, the States do not believe that the seasonality, agricultural nature, and comparatively small size of the gin sources warrants regulatory action to reduce the gins' contribution to the problem. Any gross particulate reductions made by the gins to aid in reducing the NAAQS exceedence problem would have a positive effect in reducing arsenic emissions.

In the event inorganic arsenic regulatory development is deemed necessary, close consultation and coordination between Federal and State agencies is recommended in order to produce a workable, more effective standard.

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## 8.0 GLASS MANUFACTURING

This chapter discusses the glass manufacturing industry and its associated arsenic emissions. Sections 8.1 and 8.2 present a brief source category description. Section 8.3 discusses the regulations currently covering the industry and the resulting level of control and associated arsenic emissions. Section 8.4 presents a discussion of the estimated best control (EBC) options and Section 8.5 discusses the impacts of applying these options. Section 8.6 presents the input data to be used in assessing the population exposure to arsenic emissions from glass manufacturing. The ease of standards development is discussed in Section 8.7.

### 8.1 SOURCE DESCRIPTION

This source category only includes glass manufacturing plants that use inorganic arsenic compounds as a process raw material. The only sector of the glass industry that presently uses inorganic arsenic raw materials is classified under the Standard Industrial Classification (SIC) code 3229, Pressed and Blown Glass Not Elsewhere Classified.[1] There are about 150 plants in SIC code 3229,[2] however, only 15 plants have been found to currently be emitting inorganic arsenic. These 15 plants have a total of 30 glass melting furnaces emitting arsenic. In 1978 a detailed EPA survey indicated that 17 glass plants were emitting inorganic arsenic, however, one of these plants no longer uses arsenic and one has been closed down.[3,4] The companies that currently operate glass plants emitting inorganic arsenic are Anchor Hocking, Inc., Corning Glass Works, Owens-Illinois, RCA-Picture Tube Division, and the Lamp Division of GTE Sylvania. Table 8-1 lists the locations of glass plants emitting inorganic arsenic.

The primary types of glass where arsenic is used include lead, opal, lead silicate, borosilicate and aluminosilicate-ceramic (Pyroceram®). Inorganic arsenic compounds are used in glass manufacturing for a combination of reasons depending on the particular glass being produced. In the majority of cases arsenic compounds act as fining or clarification agents. During the melting of the glass batch raw materials, gaseous reaction products such as oxygen, nitrogen, and carbon dioxide are evolved and rise through the glass melt in the form of bubbles. These bubbles greatly reduce the overall quality of the glass. The addition of the inorganic arsenic material causes the bubbles to rise more rapidly to the melt surface and dissipate. It also appears that chemical reactions brought about by the use of the arsenic reduces the release of some bubbles caused by nitrogen and carbon dioxide.[5]

A second function of arsenic in glass is to act as a decolorizing agent. The effectiveness of arsenic trioxide in this use is based on the

## TABLE 8-1. GLASS MANUFACTURING PLANTS EMITTING INORGANIC ARSENIC[a]

| PLANT NAME, LOCATION | PRIMARY PRODUCTS |
|---|---|
| RCA, Circleville, OH | TV Picture Tube Components |
| GTE, Versailles, KY | Glass Tubing |
| Owens-Illinois, Columbus, OH | TV Picture Tube Components |
| Anchor Hocking, Lancaster, OH | Tableware Glass |
| Anchor Hocking, Baltimore, MD | Container Glass |
| A | Heat Resistant Globes, Electric Light Covers |
| B | Lead Glasses |
| C | Tableware Glass |
| D | TV Picture Tube Components |
| E | Optical Glasses |
| F | TV Picture Tube Components |
| G | Tableware Glass |
| H | Glass Tubing |
| I | Aluminosilicate (Pyroceram®) and Lead Glasses |
| J | Lead Crystal Glass |

[a] Plants A through J coded at the request of manufacturer, locations available from the Strategies and Air Standards Division of EPA.

ease of interconversion of the various oxidation stages.[5] This interconversion helps establish a concentration of arsenic pentoxide under the equilibrium conditions of the melt. Arsenic pentoxide oxidizes divalent iron impurities in the melt (which impart a greenish color to the glass) to a trivalent iron, which results in a yellowish color glass. The simultaneous addition of other elements such as nickel oxide, cobalt oxide, and rare earth oxides provides balancing colors which produce a colorless finished glass.[5]

Inorganic arsenic is also used in some instances in special glass types to impart particular properties that are needed for the end use of the glass. For example, arsenic can provide stable fixation of certain colors for optical glass by stabilizing selenium, provide high glass permeability to infrared light for camera lenses, and provide a high degree of energy transmission for solar collector glass.[5]

With the advent of environmental and occupational health laws for inorganic arsenic in the late sixties and early seventies, glass companies began reducing arsenic usage and initiating research into arsenic substitutes. In 1968 approximately 3900 Mg (4300 tons) of arsenic (elemental) were used, while in 1981 total usage was estimated at 730 Mg (800 tons).[6,7] Five percent of the total arsenic consumed in the United States goes into glass production.[6] Several manufacturers of television picture tube funnel glass have totally eliminated inorganic arsenic compounds from the feed batch raw materials.[8,9] Another manufacturer reports that since 1978 arsenic usage was reduced 50 percent in a fluoride opal glass and 30 percent in a borosilicate glass.[8]

## 8.2 PROCESS DESCRIPTION

The production of an arsenic glass involves melting a uniform mixture of raw materials in a furnace to obtain a homogeneous mass. Typical materials include sand, limestone, soda ash, feldspar, sodium sulfate and nitrate, anhydrous borax, potassium carbonate, and arsenic trioxide or arsenic acid. Arsenic compounds may be introduced into the batch as either arsenic trioxide powder or liquid arsenic acid with no effect on the overall glass making process. Inorganic arsenic is also introduced into the batch feed as a constituent of the return cullet or scrap glass. The level of inorganic arsenic in the cullet is the same as the percent retained in the glass of the total batch fill.[11]

The batch raw materials are mixed and entered in the melt furnace where they float on a bed of molten glass until they dissolve. The temperature of the melt furnace is approximately 1500 to 1700°C (2700 to 3100°F).[12] The majority of the input inorganic arsenic is permanently fixed in the molten glass and is not emitted from the furnace. Data submitted by the glass industry indicates that from 70 to 99 percent of the total arsenic in the batch material remains in the glass.[11,13,14] The average percent of arsenic retained as reported by three specialty glass producers was about

94 percent. The remaining arsenic material in the form of arsenic trioxide is evaporated from the furnace melt and is either eventually emitted as arsenic vapor or it condenses as submicron arsenic particles or on other particulate matter.[5,15,16] Arsenic emissions from uncontrolled and controlled plants are affected by the size of the particular glass furnace, the type of glass produced, the type of controls used, and the size of the controls used. The majority of the arsenic particulate matter is entrained in the exhaust flue gas, however, a small portion can be deposited as particle fallout in the refractory checkerwork of the furnace.[11,13] The amount of arsenic being emitted to the atmosphere as a function of the amount in the batch feed has not been quantified.

Inorganic arsenic emissions from the glass manufacturing process are influenced by the type of furnace used to melt the batch feed raw materials. The majority of existing plants producing arsenic-containing glass use either regenerative- or recuperative-type furnace systems. The two types of furnaces differ primarily in the method by which they recover heat from the hot furnace exhaust gases. Regenerative furnaces utilize two chambers of refractory material called checkerwork. At any one time, while combustion flue gases heat the refractory in one checkerwork chamber, the other checkerwork preheats furnace combustion air. After intervals ranging from 10 to 30 minutes, this gas flow is diverted so that combustion air is drawn through the chamber previously heated by flue gases, and flue gases heat the refractory in the other chamber previously used to preheat combustion air. Recuperative furnaces use one continuously operating shell and tube type heat exchanger to preheat combustion air instead of the checkerwork heat exhangers used in the regenerative furnaces.[12,16,17] In the United States regenerative-type furnaces predominate. In regenerative furnaces, arsenic that has condensed on larger particles may be deposited in the checkerwork from particle fallout. The extent to which arsenic may be removed in the checkerwork has not been quantified. Recuperative furnaces would not have a similar arsenic removal capability.

Regenerative and recuperative furnaces, which are fossil-fuel fired, are being modified and in some cases replaced by systems using electrical current to melt glass. Electric boosting is the term applied to the furnace modification in which an electric current is used to augment furnace firing of gas or oil. Electrical energy is converted to heat because of the high electrical resistence of the molten glass. The effect of electric boosting is to decrease the required furnace bridgewall temperature, which in turn decreases the fuel consumption rate, thereby decreasing the pollutant emission rate.[18]

In some limited applications more traditional regenerative furnaces have been totally replaced by systems known as all-electric melters. All-electric melters produce less than 10 percent of the glass in the United States and none of the units produce more than 136 Mg (150 tons)/day.[19] The surface of the melter in a cold top all-electric furnace is maintained at ambient temperature and fresh batch raw materials are continuously fed over the entire surface. Because energy is supplied internally to the glass, a higher percentage of the total energy expended can be converted into usable heat for melting than with fossil fuel fired melters.[19] Pollutant emissions from all-electric melters are virtually nil.[19,20,21,22] The main limitation with these systems is that they cannot be used to produce all varieties of glass. Not all glasses possess the electrical properties required for these melters and some glass formulations actually corrode the electrodes presently used in the all-electric melters.[23]

A second source of inorganic arsenic emissions is the raw materials handling part of the glass plant where powdered arsenic trioxide is received. Fugitive arsenic dust emissions from raw materials handling are highly controlled due to OSHA regulations for airborne inorganic arsenic in the workplace. The situation here is analogous to the arsenic emissions from arsenic trioxide handling in the arsenic chemical industry (see Chapter 9). The glass industry uniformly controls these fugitive arsenic dust emissions by enclosing the unloading, conveying, and storage areas and venting them to fabric filters.[24,25] As demonstrated in the arsenic chemical industry (Chapter 9), this type of control method is effective in lowering arsenic emissions to negligible levels.

The OSHA regulations are the primary reason that some glass companies have switched from using powdered arsenic trioxide to liquid arsenic acid. By using the liquid arsenic acid as a batch raw material, no arsenic is released into the workplace. One manufacturer has indicated that they now use only liquid arsenic acid for their glass manufacturing in order to protect their workers and comply with the OSHA standard.[26] Because this source of potential arsenic emissions is already controlled with the estimated best technology and the arsenic emissions are orders of magnitude less than controlled process arsenic emissions, it will not be discussed further in this chapter.

## 8.3 INORGANIC ARSENIC EMISSIONS OCCURRING UNDER EXISTING REGULATIONS

### 8.3.1 Regulatory Impacts

Atmospheric inorganic arsenic emissions from glass plants are presently being controlled indirectly as a result of State and Federal particulate matter regulations.[27,28,29] The particulate matter regulations are met by installing an add-on control device, installing an electric boosting process modification, or collecting particulate matter as fallout in the furnace checkerwork. Of these particulate control methods, the use of add-on control devices does the best job of reducing arsenic emissions, while the checkerwork fallout technique does the worst. Discussions with the companies involved in this source category and State air pollution control representatives indicate that the plants in Table 8-1 are in compliance with applicable particulate matter regulations. However, arsenic emissions from the facilities that do not have add-on controls are significant when compared with the arsenic emission rates of plants with control devices.

None of the plants in Table 8-1 are specifically regulated for atmospheric emissions of inorganic arsenic.

### 8.3.2 Baseline Inorganic Arsenic Emissions and Controls

The estimated hourly and annual inorganic arsenic emissions from existing glass plants producing arsenic-containing glass are given in Table 8-2. The majority of the emission estimates were provided by the companies involved. Total existing arsenic emissions from the source category are about 51 Mg (56 tons)/yr. As discussed in Section 8.2, on the average only about 6 to 10 percent of the arsenic in the glass furnace melt is emitted with the furnace exhaust gases. The remaining 90 to 94 percent is fixed in the glass material. The high temperatures of the melt volatilize arsenic into the furnace offgas stream. Before the offgas stream is emitted to the atmosphere it will be cooled down by heat losses in the ductwork, by its passage through the heat recovery checkerwork, and possibly by applying a gas cooling chamber. Upon cooling some of the arsenic in the gas stream will condense and form submicron arsenic particles or will condense on other particles in the stream. Test data on the uncontrolled exhaust gas streams of two typical regenerative furnaces indicated that from 80 to 92 percent of the arsenic found was in particulate form.[30,31] The remainder is emitted into the atmosphere as vaporized arsenic.

Because inorganic arsenic emissions from glass plants are not specifically regulated, baseline arsenic emission levels are equal to the levels generated as a result of existing particulate matter regulations. The worst situation for arsenic emissions occurs when existing plants are able to rely on particle fallout in the heat recovery checkerwork as the means of complying with State particulate matter regulations. In this case the flue gas is at a high temperature as it passes through the checkerwork such that little or no arsenic would be condensing and forming particulate matter. No arsenic particle fallout would occur because the submicron particles would not likely be caught by the checkerwork. This method of particulate control is used in at least two existing arsenic glass plants.[35]

The second method that is used to reduce particulate and arsenic emissions is the electric boosting process modification. The use of electric boosting has been demonstrated to reduce overall particulate and arsenic emissions.[29] One company's experience with boosting indicated that reductions of from 30 to 60 percent were achievable when compared to uncontrolled emissions.[29] The use of electric boosting reduces arsenic emissions because it lowers the required furnace bridgewall temperature such that less material evaporation occurs. Also, the offgas temperature would be reduced, thereby promoting a greater amount of condensation and less vapor loss.

The arsenic glass plants that use add-on fabric filter or electrostatic precipitator (ESP) control devices do the best job of controlling inorganic arsenic emissions. As shown in Table 8-2, ESP devices predominate in this

## TABLE 8-2. ESTIMATED INORGANIC ARSENIC EMISSIONS AND PARTICULATE CONTROLS FOR EXISTING ARSENIC GLASS PLANTS[e]

| Plant | Existing PM Controls that Reduce Arsenic Emissions[c] | Baseline Arsenic Emissions[a] | | | |
|---|---|---|---|---|---|
| | | kg/hr | (lb/hr) | Mg/yr | (ton/yr) |
| RCA Circleville, OH | ESP preceded by evaporative cooler, 99% efficient on arsenic | 0.0036 | (0.008) | 0.032 | (0.035) |
| GTE, Versailles, KY | ESP, 95% overall efficiency | 0.0082 | (0.018) | 0.069 | (0.076) |
| Owens-Illinois, Columbus, OH | ESP, 96% overall efficiency | 0.011 | (0.025) | 0.089 | (0.101) |
| Anchor Hocking, Lancaster, OH | None[d] | 2.59 | (5.7) | 21.8 | (24)[b] |
| Anchor Hocking, Baltimore, MD | None[d] | 0.54 | (1.2) | 4.5 | (5)[b] |
| A | FF, 93% efficient on arsenic | 0.023 | (0.051) | 0.19 | (0.21)[b] |
| B | ESP, 95% overall efficiency | 0.006 | (0.013) | 0.026 | (0.028) |
| C | EB, 60% reduction on arsenic | 1.81 | (4.0) | 15.2 | (16.8)[b] |
| D | EB, 50% reduction on arsenic | 0.45 | (1.0) | 3.78 | (4.2)[b] |
| E | None | 0.0045 | (0.01) | 0.038 | (0.042)[b] |
| F | ESP preceded by an evaporative cooler, 99% efficient on arsenic | 0.0027 | (0.006) | 0.023 | (0.025)[b] |
| G | ESP preceded by a spray dryer and cyclones | 0.699 | (1.52) | 3.81 | (4.2) |
| H | ESP's preceded by evaporative cooler | 0.027 | (0.06) | 0.237 | (0.26) |
| I | FF's and EB | 0.096 | (0.21) | 0.80 | (0.88) |
| J | None | 0.014 | (0.03) | 0.118 | (0.126)[b] |

[a] Emissions expressed as total elemental arsenic.

[b] For plants where no information was available on the hours of operation 8,400 hr/yr was assumed.

[c] FF = fabric filter
ESP = electrostatic precipitator
EB = electric boosting
PM = particulate matter

[d] No controls on arsenic glass furnaces.

[e] References 10, 27, 28, 29, 30, 31, 32, 33

sector of the glass industry. Testing performed by industry and EPA has shown that ESP devices can reduce arsenic emissions by 95 to 99 percent.[10,29,31] One company noted that its "needle design" ESP is particularly efficient at removing arsenic and lead from their plant's furnace exhaust gases. Based on the company's domestic experience with the ESP and other similar experience in Japan, they believe the needle design to be more effective in this application than a "plate design" ESP.[10] The only other particulate control device used in this source category is a fabric filter. Fabric filter devices have been shown to be at least 93 percent efficient at specifically removing arsenic from glass furnace exhausts.[29,30] One manufacturer noted that cost and plant space limitations were two important factors in choosing an add-on control device, particularly since these devices are not currently installed specifically for arsenic control.[26]

As shown in Table 8-2, some facilities use gas cooling devices prior to their add-on control device for the purposes of lowering the stream temperature to prevent damage to the device and to reduce the amount of material that escapes the control device as a vapor. In the plants that use gas coolers, water evaporative-type coolers are commonly found.[29] In one source test of an arsenic glass plant with an evaporative gas cooler in place prior to its ESP, the form of the arsenic in the control device inlet stream was essentially 100 percent particulate.[31]

## 8.4 DEFINITION OF EBC OPTIONS

Of the three techniques described in Section 8.3.2, which are specifically installed for gross particulate control, only one, the use of add-on control devices, does an effective job of reducing inorganic arsenic emissions from glass furnaces. Electrostatic precipitator devices are by far the most predominant add-on control device used in the arsenic glass plant source category. However, fabric filter devices are also in place, but they have not demonstrated an arsenic removal performance equal to that of ESP's. The EPA tests on two glass plants, one with a fabric filter and the other with an ESP/gas cooler, demonstrated that the ESP system was 99 percent efficient for arsenic removal, while the fabric filter was only about 93 percent efficient.[30,31] Despite operating at a lower temperature (138°C compared to 204°C), the fabric filter system yielded an outlet arsenic concentration that was six times higher than that measured from the ESP/gas cooler system.[30,31] However, any comparisons between the use of ESP's and fabric filters to control arsenic emissions should include an examination of the type of glass produced, as this will influence the type of arsenic-containing particles to be collected. ESP's have been proven to be effective at controlling lead glass particulates, while fabric filters are more effective on borosilicate particulates due to the higher electrical resistivity of the borosilicate particles. There are, however, plants with furnaces producing multiple types of glass including lead, borosilicate, and aluminosilicate that are controlled by ESP's.[29]

Despite the fact that both ESP's and fabric filters are effective at controlling glass furnace arsenic emissions, ESP's were selected as the EBC for the purposes of the analyses in this report. In the arsenic glass plants examined ESP's predominated and they demonstrated higher arsenic removal efficiencies. The selection of ESP's as EBC does not preclude the use of fabric filters as EBC in situations where the glass particle resistivity hinders the effectiveness of ESP use.

In addition to applying an add-on control device after the melt furnace, it is recommended that the EBC option include the use of a gas cooling device to reduce the amount of arsenic emitted in vapor form. Tests at a typical arsenic glass plant equipped with an evaporative cooler demonstrated the effectiveness of cooling the offgas stream in that only 0.1 percent of the arsenic entering the plant's ESP was in a vapor form.[31] The temperature of the furnace offgas stream was not measured in this test, but the temperature at the inlet to the plant's ESP was about 209°C (408°F). As discussed in Chapter 2, at this temperature significant amounts of arsenic trioxide would be expected to be in a vapor form. However, because of the ready conversion between oxidation stages of arsenic trioxide ($As_2O_3$) and arsenic pentoxide ($As_2O_5$), the less volatile, pentavalent arsenic oxide may predominate in the offgas stream.[5] Arsenic trioxide is oxidized to arsenic pentoxide initially in the glass melt by other melt components including nitrates. At the elevated temperatures of the glass melt the arsenic pentoxide releases oxygen to perform its clarification function and arsenic trioxide results.[5] The extent to which this series of reactions is carried to completion could determine the levels of $As_2O_3$ and $As_2O_5$ in the furnace offgases. One source, in fact, reports that a borosilicate arsenic glass furnace emits primarily arsenic pentoxide.[28] The possible predominance of the pentavalent arsenic oxide may explain why essentially all of the arsenic was in the particulate form even at 204°C (400°F).

The recommended EBC option to reduce inorganic arsenic emissions from glass plants involves cooling down the melt furnace offgases by standard gas cooling devices to minimize the amount of vaporized arsenic, and then directing the arsenic particulate matter to an ESP control device. Because of a lack of test data on glass plants with gas coolers, it is difficult to estimate the optimum cooling temperature that needs to be achieved. The one plant that has been tested uses a cooler to lower the gas stream temperature to about 204°C (400°F). An analysis of the sampling train filter and impinger sections indicated that over 99 percent of the arsenic was found in a particulate form.[31] Based on the information received during this study, three of the arsenic glass plants given in Table 8-2 are using EBC including RCA-Circleville, OH and plants F and H. Five other plants including GTE-Versailles, KY, Owens-Illinois-Columbus, OH, plant A, plant B, and plant E have controls in place that reduce arsenic emissions to levels comparable to plants equipped with EBC. Because EBC is not in place at the majority of arsenic glass plants, model plants need to be developed in order to estimate the typical cost incurred by various size glass plants to install EBC.

These model plants and the level of arsenic emissions under EBC will be developed in the next section.

## 8.5 DETERMINATION OF MODEL PLANTS, EBC EMISSIONS, AND THE INCREMENTAL IMPACTS OF EBC

### 8.5.1 Model Plants

Model plants for the glass manufacturing source category were developed based on data from the background information document (BID) for the glass manufacturing NSPS and actual plant data submitted by the involved companies given in Table 8-1. Stack parameters and plant production sizes for the small and medium arsenic glass model plants were taken from data given on the pressed and blown - other than soda lime glass plants in the glass NSPS document.[36] The stack parameters for the large model plant were scaled up appropriately from the small and medium plants. The 181 Mg (200 ton)/day production rate of the large facility was included because actual arsenic glass plants exist that are this size and larger.

The model plant for this source category is defined to be a single regenerative-type, fossil fuel fired glass melting furnace. The furnace is operated on basically a continuous basis. Due to the proprietary nature of information concerning furnace operations for particular glass types (e.g., lead, borosilicate, Pyroceram®, etc.), no specific glass is assumed to be manufactured by the model plant. Instead, it is assumed that either powdered arsenic trioxide or liquid arsenic acid is added to the batch raw materials that enter the furnace and an arsenic-containing glass is produced.

The arsenic emission rates for each model plant are based on actual plant arsenic emission rates for glass plants that are approximately the same size as the model plants. This simple procedure for estimating model plant arsenic emissions had to be followed because no data were available on the amounts of arsenic input to the glass making process and on the amounts retained in the glass for the various plants in this source category. The glass companies hold these data to be business proprietary. Without these data a material balance approach to estimating model plant arsenic emissions was not possible. The arsenic emission rates and emission stack parameters of the model plants are given in Table 8-3. The existing arsenic emission rates in Table 8-3 are assumed to be occurring as a result of no gas cooling equipment and no add-on control devices being applied. The glass model plant is, however, assumed to be in compliance with applicable State particulate regulations. These assumed conditions represent the conditions of existing glass plants that have the highest levels of arsenic emissions.

In the following sections the environmental, energy, and economic impacts of the recommended EBC option on the model glass plants will be assessed. For the glass plants in Table 8-2 that have poor arsenic control,

## TABLE 8-3. GLASS MANUFACTURING MODEL PLANT PARAMETERS AND INORGANIC ARSENIC EMISSIONS

| | Small Model Plant | Medium Model Plant | Large Model Plant |
|---|---|---|---|
| Production, Mg (ton)/day glass pulled | 45.4 (50) | 90.7 (100) | 181.4 (200) |
| Baseline Arsenic Emissions, kg/hr (lb/hr) | 0.23 (0.5) | 0.45 (1.0) | 2.27 (5) |
| EBC Arsenic Emissions, kg/hr (lb/hr) | 0.0092 (0.02) | 0.018 (0.04) | 0.091 (0.20) |
| Incremental Arsenic Reduction Attributable to EBC, kg/hr (lb/hr) | 0.22 (0.48) | 0.43 (0.96) | 2.2 (4.8) |
| Stack Height, m (ft) | 25.9 (85) | 25.9 (85) | 25.9 (85) |
| Stack Diameter, m (ft) | 1.0 (3.4) | 1.4 (4.75) | 2.1 (6.7) |
| Exit Temp., °K (°F) | 477 (400) | 477 (400) | 477 (400) |
| Flow Rate, $m^3$/sec (acfm) | 7.6 (16,000) | 15.1 (32,000) | 30.2 (64,000) |
| Flow Velocity, m/sec (fps) | 9.1 (30) | 9.1 (30) | 9.1 (30) |

estimates will be made of the potential reduction in arsenic emissions achievable from the application of the EBC option.

### 8.5.2 Incremental Impacts of the EBC Option

8.5.2.1 Environmental Impacts. The atmospheric arsenic emissions resulting from the application of the EBC option to the model glass plants are shown in Table 8-3, along with the incremental arsenic reduction attributable to EBC. The potential atmospheric arsenic emissions resulting from the application of EBC to the actual arsenic glass plants are estimated in Table 8-4. Currently, the degree to which plants control arsenic is heavily dependent on the stringency of that State's particulate matter regulations. As shown in Table 8-4, several plants have control equipment in place for particulate that results in arsenic emissions comparable to or less than those from plants designated to be using EBC. In these cases it is assumed that arsenic emissions under baseline control and EBC are equal. Arsenic emissions reductions resulting from the use of EBC are estimated to be significant in plants that are uncontrolled, including Anchor Hocking - Lancaster, OH and Baltimore, MD, plant C, plant D, and plant J and in plants that are controlled but have high temperature exhausts, including plants G and I. In plants G and I only gas cooling devices would be required to reach EBC.

No adverse water pollution impacts are assumed to occur from the use of the BAT control option. Neither the ESP nor the gas cooling device will produce wastewater. Water used in the gas cooling device would be completely evaporated during normal operation of the device.

The arsenic-containing particulate collected by the ESP could present a solid waste impact from EBC, however, it is assumed that this solid waste material is recycled to be used as a batch feed raw material. This technique of handling the ESP catch is currently practiced by plants in this source category.[13,32] Therefore, it is assumed that the EBC option would not create a solid waste problem.

8.5.2.2 Energy Impacts. The largest energy impact resulting from the EBC option involves the electrical energy consumption of the ESP control device. The annual energy requirements of the model plants for ESP operation are as follows:

- large plant: 1940 Gj ($5.4 \times 10^5$ kWh)
- medium plant: 970 Gj ($2.7 \times 10^5$ kWh)
- small plant: 480 Gj($1.3 \times 10^5$ kWh)

The derivation of these quantities is summarized in Appendix A-8. The energy requirement numbers presented here represent the incremental energy impact of the EBC option.

TABLE 8-4. ARSENIC GLASS PLANT EMISSIONS UNDER EBC

| Plant Name | Baseline Arsenic Emissions kg/hr | Baseline Arsenic Emissions (lb/hr) | EBC Arsenic Emissions kg/hr | EBC Arsenic Emissions (lb/hr) | Incremental Reduction Attributable to EBC kg/hr | Incremental Reduction Attributable to EBC (lb/hr) |
|---|---|---|---|---|---|---|
| RCA, Circleville, OH | 0.0036 | (0.008) | 0.0036 | (0.008) | 0 | |
| GTE, Versailles, KY | 0.0082 | (0.018) | 0.0082 | (0.018) | 0 | |
| Owens-Illinois, Columbus, OH | 0.011 | (0.025) | 0.011 | (0.025) | 0 | |
| Anchor Hocking, Lancaster, OH | 2.59 | (5.7) | 0.10 | (0.23) | 2.49 | (5.47) |
| Anchor Hocking, Baltimore, MD | 0.54 | (1.2) | 0.022 | (0.048) | 0.52 | (1.15) |
| A | 0.023 | (0.051) | 0.023 | (0.051) | 0 | |
| B | 0.006 | (0.013) | 0.006 | (0.013) | 0 | |
| C | 1.81 | (4.0) | 0.072 | (0.16) | 1.74 | (3.84) |
| D | 0.45 | (1.0) | 0.018 | (0.04) | 0.43 | (0.96) |
| E | 0.0045 | (0.01) | 0.0045 | (0.01) | 0 | |
| F | 0.0027 | (0.006) | 0.0027 | (0.006) | 0 | |
| G | 0.70 | (1.52) | 0.036 | (0.08) | 0.66 | (1.44) |
| H | 0.027 | (0.06) | 0.027 | (0.06) | 0 | |
| I | 0.096 | (0.21) | 0.0081 | (0.018) | 0.088 | (0.19) |
| J | 0.014 | (0.03) | 0.0006 | (0.0012) | 0.013 | (0.029) |

8.5.2.3 Control Cost Impacts. This section presents the capital and annualized costs associated with the application of the ESP/gas cooler EBC option to the glass manufacturing model plants. The actual costs for EBC calculated for the model plants represent the incremental costs of control because the EBC option is being added to and not substituted for any other means of control. The capital and annualized costs of EBC are presented in Table 8-5.[37,38] The bases for the capital and annualized costs are given in Appendix B-8.

8.5.2.4 Economic Impact Resulting From EBC. An economic impact analysis was conducted for the glass manufacturing model plants to estimate the potential impact of requiring EBC. Using the cost data in Table 8-5 and the methodology given in Appendix C, revenue and product price increases, required by glass plants to maintain the same net present values before and after the installation of EBC, were estimated.

For the purposes of determining a cost for product glass the following classifications between glass model plants were assigned:

- small model plant produces only glassware
- medium and large model plants produce only television tube and bulb blank glass.

This type of classification system was required due to the inability to estimate a single glass product price, because glass plants using arsenic produce a multitude of final products.

The annual revenue increases required by the glass model plants range from $350,000 in the glassware model plant up to $620,000 in the large television tube and bulb blank model plants. The greatest unit price increases were $22 per Mg ($20 per ton) in the glassware model plant and $15 per Mg ($14 per ton) in the small television tube and bulb blank model plants. The glassware model plant and the medium bulb blank plant demonstrated the greatest product price increases, 1.7 and 1.6 percent, respectively. The lowest product price increase was 0.7 percent in the large television tube model plant. Table 8-6 summarizes the revenue and price impacts of EBC on the glass manufacturing model plants.

To test the sensitivity of the economic impact results to the various input data, a sensitivity analysis was conducted for the glass model plants, assuming simultaneous 15 percent decreases in baseline price and annual output and a 15 percent increase in the weighted cost of capital.

In the sensitivity analysis the glassware model plant still has the greatest unit product price increase at $27 per Mg ($25 per ton). The large television tube model plant had the lowest product price increase at $12 per Mg ($11 per ton). The percent price increase ranged from 1.0 percent, in the large television model plant, to 2.4 percent in the glassware model

## TABLE 8-5. CAPITAL AND ANNUALIZED COSTS OF EBC FOR GLASS MANUFACTURING MODEL PLANTS

| Model Plant Size Mg (tons)/day pulled | Hours of Operation Per Year | EBC Equipment | Total Capital Cost of EBC[a] | Total Annualized Cost of EBC[b] | Incremental Arsenic Reduction Attributable to EBC kg/hr | (lb/hr) |
|---|---|---|---|---|---|---|
| 45.4 (50) | 8400 | Gas Cooler Followed by an ESP | $ 1.5 million | $ 381,500 | 0.22 | (0.48) |
| 90.7 (100) | 8400 | Gas Cooler Followed by an ESP | $ 2.3 million | $ 554,100 | 0.43 | (0.96) |
| 181.4 (200) | 8400 | Gas Cooler Followed by an ESP | $ 3.0 million | $ 702,500 | 0.86 | (1.92) |

[a] All costs are in last quarter 1981 dollars.

[b] The annualized cost of EBC equals the incremental cost of EBC.

TABLE 8-6. REVENUE AND PRICE IMPACTS FOR GLASS MANUFACTURERS TO ACHIEVE EBC

| MODEL PLANT | | REQUIRED REVENUE INCREASE (000 dollars) | REQUIRED UNIT PRICE INCREASE (dollars per Mg) | REQUIRED PERCENT UNIT PRICE INCREASE |
|---|---|---|---|---|
| Glassware: | Small | 350.1 | 22.00 | 1.7 |
| TV Tubes: | Medium | 490.5 | 15.41 | 1.1 |
| | Large | 620.2 | 9.75 | 0.7 |
| Bulb Blanks: | Medium | 490.5 | 15.41 | 1.6 |
| | Large | 620.2 | 9.75 | 1.0 |

plant. The revenue and product price impact of all the glass manufacturing model plants are summarized in Table 8-7.

## 8.6 POPULATION EXPOSURE DATA

The data in Table 8-8 were developed during this study for use in an air pollution dispersion model to estimate the population exposure to arsenic from glass manufacturing. The Strategies and Air Standards Division (SASD) of EPA is using these data in an ongoing effort to estimate exposure to arsenic from this source category.

## 8.7 EASE OF STANDARDS DEVELOPMENT

In the event that arsenic standards development is initiated, the task of arsenic emissions measurement would not present a problem for the glass source category. The EPA, glass companies, and State and local agencies have conducted source emission tests at glass plants to specifically measure arsenic. The methodology for measuring these emissions as they are emitted to the atmosphere is established, and the methodology has been shown to be effective and accurate. The EPA reference method generally used to measure glass plant arsenic emissions is Method 108 or a slight variation of it. Method 108 is designed for use at non-ferrous smelters where high levels of sulfur dioxide ($SO_2$) are expected. In these smelter applications solutions of hydrogen peroxide ($H_2O_2$) are used in the sampling train impingers. However, glass furnace exhausts have much lower levels of $SO_2$, therefore, water ($H_2O$) is generally substituted in the impingers for the $H_2O_2$.[39,40] The arsenic emissions caught by the sampling train are quantified through Atomic Absorption Spectrophotometry. Speciation of the arsenic materials is not necessary because no organic arsenic species are evolved from a glass melt furnace.

TABLE 8-7. SENSITIVITY ANALYSIS OF THE REVENUE AND PRICE IMPACTS FOR GLASS MANUFACTURERS

| MODEL PLANT | | REQUIRED REVENUE INCREASE (000 dollars) | REQUIRED UNIT PRICE INCREASE (dollars per Mg) | REQUIRED PERCENT UNIT PRICE INCREASE |
|---|---|---|---|---|
| Glassware: | Small | 369.2 | 26.98 | 2.4 |
| TV Tubes: | Medium | 519.7 | 19.22 | 1.6 |
| | Large | 658.3 | 12.17 | 1.0 |
| Bulb Blanks: | Medium | 519.7 | 19.22 | 2.3 |
| | Large | 658.3 | 12.17 | 1.5 |

## TABLE 8-8. INPUT DATA FOR THE POPULATION EXPOSURE ASSESSMENT FROM GLASS MANUFACTURING

| Plant Name | UTM Grid Coordinates |  |  | Emission Point | Baseline Emissions[a], |  | EBC Emissions[a], |  |
|---|---|---|---|---|---|---|---|---|
|  | Zone | Vertical | Horizontal |  | kg/hr | (lb/hr) | kg/hr | (lb/hr) |
| RCA,<br>Circleville, OH | 17 | 4,381.2 km | 332.1 km | Process | 0.0036 | (0.008) | 0.0036 | (0.008) |
| GTE,<br>Versailles, KY | 16 | 4,213.1 km | 697.4 km | Process | 0.0082 | (0.018) | 0.0082 | (0.018) |
| Owens-Illinois,<br>Columbus, OH | 17 | 4,421.9 km | 331.0 km | Process | 0.011 | (0.025) | 0.011 | (0.025) |
| Anchor Hocking,<br>Lancaster, OH | 17 | 4.396.5 km | 364.7 km | Process | 2.59 | (5.7) | 0.10 | (0.23) |
| Anchor Hocking,<br>Baltimore, MD | 18 | 4,347.3 km | 359.4 km | Process | 0.54 | (1.2) | 0.022 | (0.048) |
| A | 19 | 4,640.8 km | 301.8 km | Process | 0.023 | (0.051) | 0.023 | (0.051) |
| B | 16 | 4,180.7 km | 691.2 km | Process | 0.006 | (0.013) | 0.006 | (0.013) |
| C | 18 | 4,369.3 km | 243.0 km | Process | 1.81 | (4.0) | 0.072 | (0.16) |
| D | 16 | 4,508.3 km | 653.2 km | Process | 0.45 | (1.0) | 0.018 | (0.04) |
| E |  |  |  | Process | 0.0045 | (0.01) | 0.0045 | (0.01) |
| F | 18 | 4,524.0 km | 264.7 km | Process | 0.0027 | (0.006) | 0.0027 | (0.006) |

TABLE 8-8. (Continued) INPUT DATA FOR THE POPULATION EXPOSURE ASSESSMENT FROM GLASS MANUFACTURING

| Plant Name | UTM Grid Coordinates | | | Emission Point | Baseline Emissions[a], | | EBC Emissions[a], | |
|---|---|---|---|---|---|---|---|---|
| | Zone | Vertical | Horizontal | | kg/hr | (lb/hr) | kg/hr | (lb/hr) |
| G<br>(plant has 3 furnaces with multiple stacks emitting arsenic) | 17 | 4,443.5 km | 594.1 km | Process | 0.23<br>0.23 | (0.5)<br>(0.5) | 0.018 | (0.04) |
| | | | | | 0.16<br>0.07 | (0.35)<br>(0.15) | 0.009 | (0.02) |
| | | | | | 0.009 | (0.02) | 0.009 | (0.02) |
| H | | | | Process | 0.027 | (0.06) | 0.027 | (0.06) |
| I<br>(plant has 2 furnaces emitting arsenic) | | | | Process | 0.0045 | (0.01) | 0.0045 | (0.01) |
| | | | | | 0.091 | (0.20) | 0.0036 | (0.008) |
| J | | | | Process | 0.014 | (0.03) | 0.0006 | (0.0012) |

[a] Emissions expressed as total elemental arsenic.

### TABLE 8-8. (Continued) INPUT DATA FOR THE POPULATION EXPOSURE ASSESSMENT FROM GLASS MANUFACTURING

| Plant Name | Stack Parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Height, | | Diameter, | | Exit Temp., | | Flow Rate, | | Flow Velocity, | |
| | m | (ft) | m | (ft) | °K | (°F) | $m^3$/sec | (acfm) | m/sec | (fps) |
| RCA,<br>Circleville, OH | 22.3 | (73) | 1.5 | (5) | 505 | (450) | 25.3 | (53,600) | 14 | (46) |
| GTE,<br>Versailles, KY | 15.4 | (50.7) | 0.7 | (2.3) | 494 | (430) | 10.9 | (23,000) | 29.3 | (96) |
| Owens-Illinois,<br>Columbus, OH | 21.3 | (70) | 1.6 | (5.2) | 450 | (350) | 10.5 | (22,200) | 12.7 | (41.6) |
| Anchor Hocking,<br>Lancaster, OH | 25.9 | (85) | 2.1 | (6.7) | 477 | (400) | 30.2 | (64,000) | 9.1 | (30) |
| Anchor Hocking,<br>Baltimore, MD | 25.9 | (85) | 1.4 | (4.75) | 477 | (400) | 15.1 | (32,000) | 9.1 | (30) |
| A | 18.3 | (60) | 0.91 | (3) | 412 | (282) | 3.2 | (6,800) | 4.9 | (16.1) |
| B | 41.1 | (135) | 1.8 | (5.9) | 440 | (333) | 12.9 | (27,300) | 4.5 | (14.8) |
| C | 41.1 | (135) | 2.4 | (8) | 666 | (740) | 17.0 | (36,000) | 3.4 | (11) |
| D | 41.1 | (135) | 2.1 | (7) | 672 | (750) | 28.3 | (60,000) | 7.6 | (25) |
| E | 25.9 | (85) | 1.0 | (0.34) | 477 | (400) | 7.6 | (16,000) | 9.1 | (30) |
| F | 41.1 | (135) | 1.6 | (5.2) | 482 | (409) | 28.4 | (60,100) | 14.3 | (47) |

### TABLE 8-8. (Continued) INPUT DATA FOR THE POPULATION EXPOSURE ASSESSMENT FROM GLASS MANUFACTURING

| Plant Name | Stack Parameters | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Height, | | Diameter, | | Exit Temp., | | Flow Rate, | | Flow Velocity, | |
| | m | (ft) | m | (ft) | °K | (°F) | $m^3$/sec | (acfm) | m/sec | (fps) |
| $G_1$ Furnace 1 | 9.1 | (30) | 0.76 | (2.5) | 672 | (750) | 6.1 | (13,000) | 13.4 | (44) |
| | 7.6 | (25) | 0.76 | (2.5) | 755 | (900) | 8.3 | (17,500) | 18.3 | (60) |
| $G_2$ Furnace 2 | 15.2 | (50) | 0.82 | (2.7) | 644 | (700) | 16.3 | (34,600) | 31.4 | (103) |
| | 9.1 | (30) | 0.76 | (2.5) | 561 | (550) | 6.3 | (13,400) | 14.3 | (47) |
| $G_3$ Furnace 3 | 30.5 | (100) | 1.2 | (4) | 477 | (400) | 20.2 | (42,700) | 17.4 | (57) |
| H | 25.9 | (85) | 2.1 | (6.7) | 477 | (400) | 15.1 | (32,000) | 9.1 | (30) |
| $I_1$ Furnace 1 | 25.9 | (85) | 1.0 | (3.4) | 477 | (400) | 7.6 | (16,000) | 9.1 | (30) |
| $I_2$ Furnace 2 | 27.4 | (90) | 1.1 | (3.7) | 755 | (900) | 14.2 | (30,000) | 14 | (46) |
| J | 25.9 | (85) | 1.0 | (3.4) | 477 | (400) | 7.6 | (16,000) | 9.1 | (30) |

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## 9.0 ARSENIC CHEMICAL PRODUCTION

This chapter discusses the arsenic chemical manufacturing industry and its associated arsenic emissions. Section 9.1 presents a brief source category description. Section 9.2 discusses the regulations currently covering the industry and the resulting level of control and associated arsenic emissions. Section 9.3 presents a discussion of the estimated best control (EBC) options and Section 9.4 gives the input data to be used in assessing the population exposure to arsenic emissions from arsenic chemical manufacturing.

### 9.1 SOURCE DESCRIPTION

The manufacture of chemicals containing arsenic is an obvious potential source of atmospheric inorganic arsenic emissions. As many as 25 arsenic-containing chemicals are produced, of which 18 are inorganic and seven organic in nature.[1] These chemicals are identified in Table 9-1. The organic chemicals are included in this discussion because inorganic arsenic compounds are used in the production of organic arsenicals and may be emitted during raw materials handling and process reaction steps. Arsenic chemical production consumes approximately 90 percent of the total arsenic used in the United States. Of this 90 percent, about 70 percent goes into pesticides manufacture and 20 percent to wood preservative manufacture.[2]

Nine of the compounds given in Table 9-1 are considered to be of major importance because they constitute 90 to 95 percent of the production in the arsenic chemicals industry.[3,4,5] The nine chemicals are as follows:

- orthoarsenic acid
- monosodium methylarsonate (MSMA)
- disodium methylarsonate (DSMA)
- dimethylarsinic acid (cacodylic acid)
- calcium arsenate
- lead arsenate
- sodium arsenite
- chrome copper arsenate (CCA)
- ammoniacal copper arsenite (ACA)

The production of these nine chemicals will be discussed in depth in the following section.

## TABLE 9-1. ARSENIC COMPOUNDS AND THEIR USE

| ARSENIC COMPOUNDS | MAJOR USE |
|---|---|
| INORGANIC | |
| Orthoarsenic Acid | Desiccant |
| Arsenic Disulfide (tri and penta) | Textile painting |
| Arsenic Iodide (arsenous iodide) | Antiseptic |
| Arsenic Pentafluoride | Laboratory Research |
| Arsenic Thioarsenate | Scavenger |
| Arsenic Tribromide (arsenous bromide) | Medicinals |
| Arsenic Trichloride (arsenous chloride) | Herbicide |
| Arsenic Trifluoride (arsenous fluoride) | Laboratory Research |
| Arsenic Trioxide (arsenous oxide, arsenous acid) | Arsenical Precursor |
| Arsine (arsenous hydride) | Semiconductor Industry |
| Calcium Arsenate | Insecticide |
| Calcium Arsenite | Insecticide |
| Copper Arsenate | Wood Preservative |
| Copper Arsenite | Insecticide |
| Lead Arsenate | Insecticide |
| Sodium Arsenate | Herbicide |
| Sodium Arsenite | Herbicide |
| Zinc Arsenate | Insecticide |
| ORGANIC | |
| Arsanilic Acid (sodium arsanilate) | Feed Additive |
| Cacodylic Acid (dimethylarsinic acid) | Defoliant |
| Fluor Chrome Arsenate Phenol | Wood Preservative |
| Methanearsonic Acid (mono- and disodium salts, MSMA/DSMA) | Herbicide |
| Methanearsonic Acid (calcium salts) | Herbicide |
| Methanearsonic Acid (ammonium salts) | Herbicide |
| Copper Acetoarsenite (Paris green) | Insecticide |

### 9.1.1 Orthoarsenic Acid

Orthoarsenic acid ($H_3AsO_4$) functions as both an end product and as a chemical intermediate to the production of other inorganic and organic arsenicals. As an end product arsenic acid is used as an agricultural desiccant/defoliant. It is primarily used to desiccate short-season cotton that will be harvested by a mechanical stripping technique. Desiccation of the cotton plant is required to prevent plant moisture from staining the cotton fibers prior to ginning, and thereby, lowering the quality grade of the product cotton.[6,7,8] It also has other uses as a glass manufacturing raw material.

Arsenic acid is manufactured by reacting powdered arsenic trioxide with nitric acid. The reaction is generally carried out as a batch process in a variety of reactor vessels. An example process flow sheet is given in Figure 9-1. Reactor types may vary from pressurized, temperature controlled vessels to simple stirred tank reactors operating at ambient conditions. Arsenic trioxide ($As_2O_3$) generally arrives at the facility in drums. The handling and unloading (dumping) of the arsenic trioxide powder constitutes the primary source of inorganic arsenic emissions from arsenic acid manufacture. The arsenic trioxide drums are dumped into storage bins or directly into the materials coveying system. The action of dumping the fine powder creates fugitive dust emissions. These inorganic arsenic emissions are well-controlled by existing plants primarily to comply with OSHA regulations and to recover the arsenic trioxide for process use.[9,10,11] The majority of plants are also affected to some degree by State particulate matter regulations. The methods of trioxide emissions control are discussed in detail in Section 9.2.2.

Because the demand for arsenic trioxide exceeds the supply of the sole domestic producer (ASARCO), quantities must be imported from Mexico, Sweden, and England to make up the difference. This situation of tight supply motivates companies towards arsenic trioxide raw material recovery and reuse. One major arsenical manufacturer indicated that they would like to produce more arsenic acid but could not due to the shortages of arsenic trioxide.[11]

Besides the raw materials handling step, other process steps in the production of arsenic acid such as the arsenic trioxide-nitric acid reaction, product purification, and product packaging, may be sources of atmospheric inorganic arsenic emissions. However, compared to the raw materials handling step, inorganic arsenic emissions from the process reaction, product purification, and product packaging steps are negligible or non-existent.[12] This is true because these process steps involve handling wet, low temperature arsenic materials, therefore, no dust problem exists and no arsenic volatilization occurs.

Two companies in the United States manufacture liquid arsenic acid as their chemical end product. These companies are the Agchem Division of

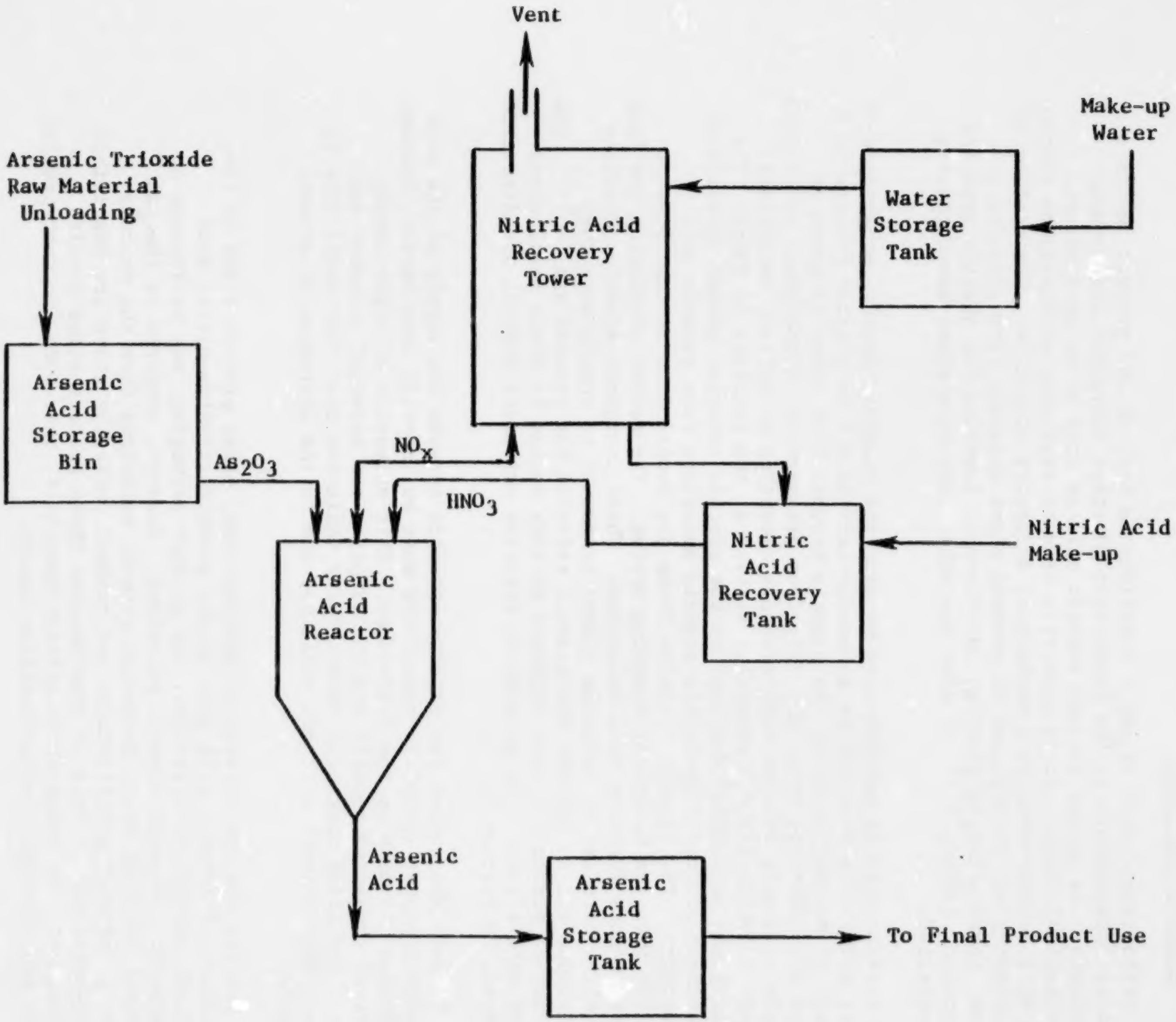
Vent
Make-up Water
Arsenic Trioxide Raw Material Unloading
Nitric Acid Recovery Tower
Water Storage Tank
Arsenic Acid Storage Bin
$As_2O_3$
$NO_x$
$HNO_3$
Arsenic Acid Reactor
Nitric Acid Recovery Tank
Nitric Acid Make-up
Arsenic Acid
Arsenic Acid Storage Tank
To Final Product Use

Figure 9-1. Arsenic acid production process.

Pennwalt Corporation in Bryan, Texas and the Voluntary Purchasing Group (VPG) in Bonham, Texas.[11,13] In 1980, VPG produced about 2.27 million liters (600,000 gal) of arsenic acid, while in 1981 Pennwalt manufactured approximately 2.65 million liters (700,000 gal) of the same compound.[11] Three other companies, Koppers Company, Mineral Research and Development Corporation, and Osmose Wood Preserving Company all manufacture arsenic acid as a chemical intermediate to the production of arsenical wood preservatives (chrome copper arsenate and ammoniacal copper arsenite). The arsenic acid produced by these companies is used for in-house captive purposes only and is not sold on the open market.[11,14,15]

### 9.1.2 MSMA, DSMA, and Cacodylic Acid

The production of MSMA, DSMA, and cacodylic acid arsenicals is important in assessing inorganic arsenic emissions because arsenic trioxide is in most cases the starting material for these end product chemicals. MSMA and DSMA are selective herbicides for post-emergent weed control of grassy weeds in cotton, citrus, turf, and non-crop areas.[7] Cacodylic acid is a non-selective, post-emergent herbicide that is chiefly used in lawn renovation and weed control in non-crop areas. Cacodylic acid also has significant uses as a defoliant particularly for machine-picked cotton in California and Arizona.[7]

These three chemicals are frequently grouped together because they are manufactured by a relatively similar process. The major difference in determining the end product is the number of reaction steps and the utilization of side-reactions.[4] The process starts by manufacturing DSMA by reacting arsenic trioxide with sodium hydroxide and water to form sodium arsenite, which is in turn treated under pressure with methyl chloride to form DSMA. The DSMA may then be removed and sold as a herbicide or further reacted to form MSMA. To produce MSMA sulfuric acid is added to DSMA to adjust the pH. This material is then centrifuged to remove sodium chloride and sodium sulfate waste salts and the resulting MSMA solution is concentrated by evaporating the water.

To produce cacodylic acid, sulfur dioxide is first added to the methanearsonic acid (acidified DSMA) to reduce this to the trivalent form. A second methylation with methyl chloride is then performed yielding cacodylic acid. As with MSMA, waste salts are removed, the filtrate evaporated to the desired concentration, and unreacted trivalent arsenic species are oxidized.[16,17] A schematic of the overall production process for DSMA, MSMA, and cacodylic acid is given in Figure 9-2.[16]

The primary points of potential inorganic arsenic emissions during the manufacture of the organic arsenicals are the arsenic trioxide handling area and the sodium arsenite process unit. Only two companies manufacture these organic arsenicals such that inorganic arsenic is emitted. These companies are Diamond Shamrock Corporation (Agricultural Chemicals Division) in Greens Bayou, Texas and Vineland Chemical Company in Vineland, New Jersey. Diamond

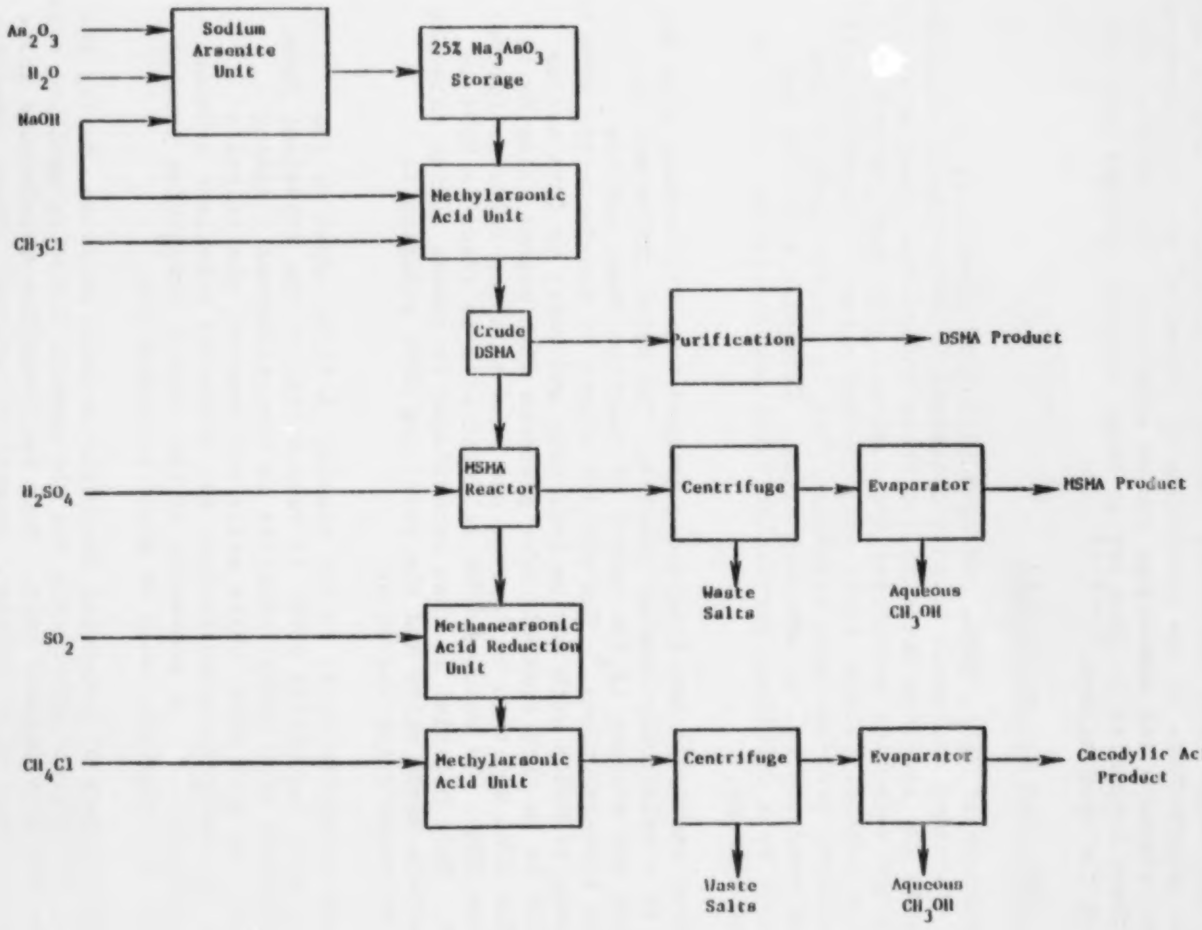
$As_2O_3$
$H_2O$
NaOH
$CH_3Cl$
$H_2SO_4$
$SO_2$
$CH_4Cl$
Sodium Arsenite Unit
25% $Na_3AsO_3$ Storage
Methylarsonic Acid Unit
Crude DSMA
Purification
DSMA Product
MSMA Reactor
Centrifuge
Evaporator
MSMA Product
Waste Salts
Aqueous $CH_3OH$
Methanearsonic Acid Reduction Unit
Methylarsonic Acid Unit
Centrifuge
Evaporator
Cacodylic Acid Product
Waste Salts
Aqueous $CH_3OH$

Figure 9-2. Production schematic for DSMA, MSMA, and cacodylic acid.

Shamrock's primary product is MSMA with very little DSMA and no cacodylic acid being manufactured. Vineland produces all three chemicals and is the only domestic manufacturer of cacodylic acid.[10] Inorganic arsenic emission controls are in place at both facilities and these will be discussed in detail in Section 9.2.2. Another company, W. A. Cleary, Incorporated in Somerset, New Jersey produces DSMA, but not by the method given in Figure 9-2. Instead Cleary buys MSMA and chemically reacts it to transform the compound back to DSMA. The company has been manufacturing DSMA this way for about ten years. Representatives of Cleary indicated that the company had realized early the health hazards and environmental implications of handling inorganic arsenic substances and had made the decision to not manufacture DSMA in the classical manner. No inorganic arsenic emissions are associated with the Cleary facility.[18]

### 9.1.3 Calcium Arsenate, Lead Arsenate, and Sodium Arsenite

Calcium arsenate, lead arsenate, and sodium arsenite are inorganic arsenicals that function as insecticides, herbicides, and pesticides for a variety of applications. The primary uses of each compound are given in Table 9-2.[19] Following a thorough survey of the arsenical pesticide industry it was determined that there are no domestic producers of lead arsenate, one producer of calcium arsenate, and only one producer of sodium arsenite.

Calcium arsenate was manufactured by Woolfolk Chemical Works in Fort Valley, Georgia up until 1974.[19,20] They produced calcium arsenate by starting with dry arsenic trioxide, which they reacted to form arsenic acid, and then used the acid to form the arsenate. In 1981 the company decided to start up production of calcium arsenate again, however, this time as a liquid product process and not a dry one.[21] Delays were incurred in getting the facility on-line in 1981, and the most recent Woolfolk estimates indicate that startup will not occur until the fall of 1982.[20] The process to manufacture calcium arsenate as a flowable product will proceed by reacting purchased liquid arsenic acid with lime and running the mixture through a wet grinding mill.[22] As a result of the wet processing involved, no inorganic arsenic emissions are expected from the facility.

The one current manufacturer of sodium arsenite is Sharpe Chemicals in Burbank, California.[10,23,24,25,26] Sodium arsenite is produced by reacting arsenic trioxide, sodium hydroxide, and water. Sharpe only manufactures sodium arsenite on a bench-scale basis for university teaching and research purposes. Production is intermittent and only 0.45 to 2.3 kg (1 to 5 lbs) are made during any single batch. Total annual production is less than 45.4 kg (100 lbs).[26] Because of the size of Sharpe's production and the essentially zero arsenic emissions from the company's facility, it was excluded from further examination in this study.

The most recent commercial producer of sodium arsenite was found to be Colorado Organic Chemical Company in Commerce City, Colorado. They

## TABLE 9-2. USES OF ARSENICAL PESTICIDES, INSECTICIDES, AND HERBICIDES

| COMPOUND | CROP/SITE | OBJECT OF USE |
|---|---|---|
| Calcium Arsenate | 44 different crops, flowers | Snail bait |
| | Grapefruit | Control acidity |
| | Poultry houses | Fly control |
| | Turf | *Poa annua*, soil insects |
| Lead Arsenate | Grapefruit | Control acidity |
| Sodium Arsenite | Grapes | Measles, dead arm |
| | Livestock quarantine | Texas cattle fever tick |

manufactured small batch quantities of sodium arsenite for other companies to use as an input raw material to the production of organic arsenicals. However, the company has ceased production of the arsenite and a company official has indicated that they do not plan to resume production.[23] Therefore, Colorado Organic was also excluded from further consideration.

### 9.1.4 Chrome Copper Arsenate and Ammoniacal Copper Arsenite

Until recently three arsenical wood preservatives, chrome copper arsenate (CCA), ammoniacal copper arsenite (ACA), and fluor chrome arsenate phenol (FCAP), were produced for wood fungicide purposes.[4] According to several sources FCAP is no longer being produced, and therefore, will not be considered further in this document.[10,27,28]

Of the two remaining arsenical preservatives, CCA is by far the most important. The CCA preservative is manufactured by reacting arsenic acid, chromic acid, and copper oxide. Five companies were identified that are producing CCA including: Koppers Company, Conley, Georgia and Valparaiso, Indiana; Mineral Research and Development, Concord, North Carolina; C. P. Chemicals, Sewaren, New Jersey; Osmose Wood Preserving, Memphis, Tennessee; and Chemical Specialties, Valdosta, Georgia.[10,11,27,28,29] As discussed in Section 9.1.1, three of these companies, Koppers, Mineral Research and Development, and Osmose Wood Preserving, produce their own arsenic acid to use as a reactant for their CCA production. For this reason these three companies present the greatest potential for inorganic arsenic emissions because they handle the arsenic trioxide raw material. The control mechanisms used by these companies to reduce arsenic trioxide particulate emissions are discussed in Section 9.2.2. C. P. Chemicals and Chemical Specialties do not produce their own arsenic acid. They purchase liquid arsenic acid, and therefore, do not have the problem of arsenic trioxide dust emissions.

Ammoniacal copper arsenite is only produced by one company, J. H. Baxter of San Mateo, California.[10,30] The use of ACA is almost entirely limited to the West Coast (California, Washington, and Oregon) as a fir wood preservative. The ACA preservative is manufactured by reacting arsenic acid and copper oxide. Baxter also buys liquid arsenic acid to perform all of their production. By analogy to the C. P. Chemicals and Chemical Specialties processes above, inorganic arsenic emissions would be negligible with this process.

All of the six companies in the arsenical wood preservative manufacturing sector have the potential to emit inorganic arsenic in the form of their final product (CCA or ACA) during process reaction, product storage, or product packaging steps. Again, however, arsenic emissions from these process steps would be negligible or nonexistent because only wet, low temperature materials are involved.

### 9.1.5 Summary of Producers

Although there are 14 companies involved in the production of the nine important arsenical compounds (given in Section 9.1), only seven of these companies handle dry powdered arsenic trioxide and have the potential to be significant inorganic arsenic emission sources. These seven are listed in Table 9-3.

## 9.2 INORGANIC ARSENIC EMISSIONS OCCURRING UNDER EXISTING REGULATIONS

### 9.2.1 Regulatory Impacts

The primary environmental regulations affecting atmospheric arsenic emissions from arsenic chemical plants are the particulate matter limitations discussed in Section 2.2. These types of regulations are applied because the inorganic arsenic emissions from plants in the source category are arsenic trioxide particulate dust. The particulate matter regulations generally take the form of an hourly emission limit based on process weight throughput.

For each of the eight plants given in Table 9-3, existing emissions of inorganic arsenic particulate matter are dramatically less than the allowable emissions dictated by current State particulate regulations. To illustrate this point, Table 9-4 presents the estimated existing and allowable inorganic arsenic emissions from several plants in this source category. All eight plants are in compliance with their applicable particulate regulations.

Though important, the particulate emission limitations are not the main factor motivating inorganic arsenic emissions control at arsenic chemical plants. Instead, the OSHA regulations on airborne workplace inorganic arsenic play the primary role in reducing atmospheric arsenic emissions.[9,10,11,19,34] The specific limitations of the OSHA inorganic arsenic standard are detailed in Section 2.3. The OSHA rules have motivated plants handling arsenic trioxide raw materials to install systems capable of capturing, collecting, and conveying trioxide dust to an appropriate control device in order to comply with the workplace limit of 10 $\mu g/m^3$ of inorganic arsenic. Some plants in this source category have been closed down because of the inability to keep the workplace inorganic arsenic levels below the OSHA limit.[19,34] One facility, Pennwalt in Bryan, Texas, performs voluntary monthly monitoring of arsenic levels to insure OSHA compliance.[11]

### 9.2.2 Baseline Inorganic Arsenic Controls and Emissions

The arsenic chemical plants examined in this report are in compliance with applicable EPA, SIP, and OSHA regulations, therefore, baseline arsenic controls and emissions are equivalent to currently existing controls and emissions. The control systems used in existing arsenic chemical plants consist of an emission capture system and control device.[14,31,33,35] The

TABLE 9-3. ARSENIC CHEMICAL PLANTS WITH SIGNIFICANT INORGANIC ARSENIC EMISSIONS

| PLANT NAME | LOCATION | PRIMARY PRODUCT(S) | ESTIMATED ANNUAL INORGANIC ARSENIC EMISSIONS kg/yr (lb/yr) |
|---|---|---|---|
| Diamond Shamrock | Greens Bayou, TX | MSMA, some DSMA | 0.027 (0.060) |
| Koppers Company | Conley, GA<br>Valparaiso, IN | CCA Wood Preservative | 0.020 (0.043)<br>0.009 (0.020) |
| Mineral Research & Development Corp. | Concord, NC | CCA Wood Preservative | 0.016 (0.035) |
| Osmose Wood Preserving, Inc. | Memphis, TN | CCA Wood Preservative | 39.5 (86.9) |
| Pennwalt, Inc. | Bryan, TX | Arsenic Acid | 0.0056 (0.012) |
| Vineland Chemical | Vineland, NJ | MSMA, DSMA, Cacodylic Acid | 0.0025 (0.0055) |
| Voluntary Purchasing Group | Bonham, TX | Arsenic Acid | 0.018 (0.040) |

### TABLE 9-4. COMPARISON OF EXISTING AND ALLOWABLE INORGANIC ARSENIC EMISSIONS[14,31,32,33]

| PLANT | ALLOWABLE EMISSIONS UNDER SIP PARTICULATE REGULATIONS, Mg(Tons)/yr | EXISTING EMISSIONS, Mg(Tons)/yr |
|---|---|---|
| Osmose Wood Preserving | 1.13 (1.25) | 0.039 (0.043) |
| Vineland Chemical | 1.97 (2.19) | 0.0000025 (0.0000028) |
| Mineral Research & Development Corp. | 4.14 (4.6) | 0.000016 (0.000018) |

purpose of the capture system is to collect particulate matter that can be emitted during the handling and processing of powdered arsenic trioxide raw material. The control device removes the collected arsenic particulate from the exhaust gas stream, and the material is eventually returned to the arsenic chemical process.

The eight plants of interest in this source category use a similar system to capture arsenic trioxide particulate emissions, though the exact configuration of the system varies slightly from plant-to-plant. The basic capture system involves the use of hooding or total enclosures to collect the emissions, which are in turn pneumatically conveyed to a control device. The arsenic trioxide raw material generally enters the plant in large drums which are opened and dumped by a mechanical arm in either an enclosed room or under a hooding system. Arsenic trioxide dust collected from these operations is vented to either a fabric filter or wet scrubber control device. Empty raw material drums are cleaned by vacuum pick-ups and then washed out under a collection hood to capture any remaining arsenic trioxide dust that could be displaced. Drum wash waters are returned to the process to avoid discharging any arsenic trioxide to the environment.

Of the eight plants with the potential to emit arsenic trioxide dust, three use fabric filters to control emissions, four use wet scrubbers, and one uses a fabric filter followed by a wet scrubber. Arsenic trioxide particulate emissions have been reduced by an average of 99.5 percent in the three plants using fabric filter control devices.[31,33,35] The collected arsenic trioxide is returned to the process. In addition to its primary fabric filter control device, one plant also uses a high efficiency particulate air (HEPA) filter on the exhaust gas stream from its fabric filter. The efficiency of the HEPA filter, as estimated by the plant, is 99.9+ percent.[35] When required, the HEPA filter is washed out and the wash waters returned to the arsenic chemical process.

Although no test data are available on the arsenic removal efficiency for the four plants using wet scrubbers, an examination of these plants' inorganic arsenic emision rates in Table 9-5 verifies that the scrubbing method of control is comparable to fabric filters in this application.[29,32,35] The spent scrubbing solution resulting from this control method, which contains arsenic, is returned to the arsenical process thus eliminating potential arsenic water pollution.

The remaining arsenical facility operates a fabric filter, estimated to be 99 percent efficient, to control arsenic trioxide emissions from the arsenic trioxide handling operations.[33] The exhaust stream from the fabric filter is sent to a wet scrubber before final exhaust to the atmosphere. While an across-the-device efficiency has not been determined for the scrubber by testing, the efficiency was estimated to be at least 95 percent at its installation.[33]

## TABLE 9-5. SUMMARY OF EXISTING CONTROLS AND INORGANIC ARSENIC EMISSIONS IN THE ARSENIC CHEMICAL SOURCE CATEGORY[a,b]

| PLANT | EXISTING CAPTURE AND COLLECTION CONTROLS | EXISTING CONTROL DEVICE TYPE/EFFICIENCY | EXISTING EMISSIONS OF INORGANIC ARSENIC | |
|---|---|---|---|---|
| | | | HOURLY, kg/(lb) | ANNUALLY, kg(lb) |
| Diamond Shamrock, Greens Bayou, TX | Confidential Data | Wet Scrubber/99+% | 0.000011 (0.000024) | 0.027 (0.060) |
| Koppers Company | | | | |
| Conley, GA | Confidential Data | Wet Scrubber | 0.00001 (0.000022) | 0.020 (0.043) |
| Valparaiso, IN | Confidential Data | Wet Scrubber | 0.00002 (0.000044) | 0.009 (0.020) |
| Mineral Research & Development, Concord, NC | Enclosed materials handling and dumping areas, vacuum dust pick-up system | Fabric Filter/ 99.9% | 0.000008 (0.000018) | 0.016 (0.035) |
| Osmose Wood Preserving, Inc., Memphis, TN | Enclosed materials handling and dumping areas, vacuum dust pick-up system | Fabric Filter/99% followed by a Wet Scrubber/95% | 0.019 (0.042) | 39.5 (86.9) |
| Pennwalt, Inc. Bryan, TX | Confidential Data | Confidential Data | 0.000007 (0.000015) | 0.0056 (0.012) |
| Vineland Chemical, Vineland, NJ | Hooding on all materials handling points, vacuum dust pick-up system | Wet Scrubber/99.9% | 0.0000004 (0.0000009) | 0.0025 (0.0055) |
| Voluntary Purchasing Group, Bonham, TX | Enclosed materials handling areas, vacuum dust pick-up system | Fabric Filter/99+% | 0.000007 (0.000015) | 0.018 (0.040) |

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[a] For the arsenic chemical source category, baseline controls and emissions are equivalent to existing conditions.

[b] References 11, 12, 14, 29, 31, 32, 33, 35, 36.

A summary of inorganic arsenic emissions and emission control devices for each of the eight arsenic chemical plants is presented in Table 9-5. The majority of the particulate emission rates given in the table were determined by source testing according to EPA reference methods. Annual and hourly inorganic arsenic emissions from these facilities are small. The total estimated inorganic arsenic emissions from the eight facilities examined are 39.6 kg/yr (87.1 lb/yr). One facility in Table 9-5, Osmose Wood Preserving, has higher emissions than the other plants that were studied. Controlled arsenic emissions are greater due to the comparatively larger quantity of arsenic trioxide raw material that the plant handles. As a consequence of handling more material, uncontrolled arsenic trioxide emissions from Osmose would be greater than those from the other plants. The measured arsenic emissions from the scrubber stack agree well with the emissions estimate for the plant which can be calculated from the estimated uncontrolled emission rate and the estimated control device efficiencies. These comparative calculations are detailed in Appendix A-9.

It is also important to note that inorganic arsenic emissions from this source category are not continuous. Emissions would be occurring only during periods of arsenic trioxide handling, dumping, and processing. For the arsenic chemical plants examined, the periods of arsenic trioxide handling and dumping ranged from 800 to 6240 hours per year. The length of the arsenic trioxide handling and dumping cycle is a function of the amount of arsenic trioxide used and the capacity of plant equipment.

## 9.3 DEFINITION OF EBC OPTIONS

An examination of Table 9-5 indicates that emission capture and control systems are extensively used in existing arsenic chemical plants, and they are effective in reducing atmospheric inorganic arsenic emissions. The magnitude of the arsenic emission rates in Table 9-5 signifies that EBC is in place for this source category and is represented by the control systems currently in use. The EBC system for this source category consists of a particulate emission capture system in the form of hooding or enclosures, with the collected material being pneumatically conveyed to a fabric filter or wet scrubber control device. As emphasized in Section 9.2, the need for EBC-type equipment has been dictated by OSHA workplace regulations for airborne inorganic arsenic.

Because EBC is in place in the eight arsenic chemical plants, no model plant development for the purposes of an economic analysis is required. There would be no impacts of EBC because emissions under baseline control are equivalent to emissions under EBC control.

## 9.4 POPULATION EXPOSURE DATA

The data in Table 9-6 were developed during this study for use in an air pollution dispersion model to estimate the population exposure to

## TABLE 9-6. INPUT PARAMETERS FOR THE POPULATION EXPOSURE MODELING ANALYSIS[d]

| Plant Location | Zone | UTM Grid Coordinates Vertical | Horizontal | Emission Points | Baseline Emissions kg/hr (lb/hr) | EBC Emissions, kg/hr (lb/hr) |
|---|---|---|---|---|---|---|
| Diamond Shamrock, Greens Bayou, TX | 15 | 3294.7 km | 286.7 km | Scrubber Exhaust | 0.000011<br>(0.000024) | 0.000011<br>(0.000024) |
| Koppers Company Conley, GA | 16 | 3725.8 km | 748.0 km | Scrubber Exhaust | 0.00001<br>(0.000022) | 0.00001<br>(0.000022) |
| Valparaiso, IN | 16 | 4591.4 km | 494.9 km | Scrubber Exhaust | 0.00002<br>(0.000044) | 0.00002<br>(0.000044) |
| Mineral Research & Development Corp., Concord, NC | 17 | 3918.2 km | 538.2 km | Fabric Filter Exhausts (3) | 0.000008<br>(0.000018) | 0.000008<br>(0.000018) |
| Osmose Wood Preserving Co., Memphis, TN | 15 | 3886.4 km | 766.9 km | Scrubber Exhaust | 0.019<br>(0.042) | 0.019<br>(0.042) |
| Pennwalt, Inc. Bryan, TX | 14 | 3396.3 km | 752.0 km | Control Device Exhaust | 0.000007<br>(0.000015) | 0.000007<br>(0.000015) |
| Vineland Chemical Vineland, NJ | 18 | 4420.2 km | 521.5 km | Scrubber Exhaust | 0.0000004<br>(0.0000009) | 0.0000004<br>(0.0000009) |
| Voluntary Purchasing Group, Bonham, TX | 14 | 3718.7 km | 761.9 km | Fabric Filter Exhaust | 0.000007<br>(0.000015) | 0.000007<br>(0.000015) |

## TABLE 9-6. Continued

| Plant Location | STACK PARAMETERS | | | | |
|---|---|---|---|---|---|
| | Height m (ft) | Diameter m (ft) | Exit Temperature °K (°F) | Flow Rate $m^3$/sec (acfm) | Flow Velocity m/sec (fps) |
| Diamond Shamrock<br>Greens Bayou, TX | 12.5 (41) | 0.38 (1.25) | Ambient | 3.5 (7,400) | 11.9 (39.3) |
| Koppers Company<br>Conley, GA | 30.5 (100) | 0.61 (2) | Ambient | 0.024 (50) | 0.076 (0.25) |
| Valparaiso, IN | 9.1 (30) | 0.76 (2.5) | Ambient | 0.84 (1,770) | 1.6 (5.4) |
| Mineral Research and<br>Development Corporation<br>Concord, NC | 0.39 (1.3)<br>10.8 (36.0)<br>0.39 (1.3) | a<br>b<br>c | Ambient | 0.43 (930)<br>0.14 (300)<br>0.31 (670) | 8.5 (28.1)<br>8.8 (29.0)<br>17.4 (57.4) |
| Osmose Wood Preserving Company<br>Memphis, TN | 4.5 (15) | 0.36 (1.2) | Ambient | 1.6 (3,300) | 14.3 (47.2) |
| Pennwalt, Inc.<br>Bryan, TX | 9.7[e] (32) | 0.53[e] (1.74) | Ambient | 1.9 (3,900) | 8.9 (29.5)[e] |
| Vineland Chemical<br>Vineland, NJ | 12.5[e] (41) | 0.38[e] (1.25) | Ambient | 0.040 (85) | 0.127 (0.425)[e] |
| Voluntary Purchasing Group<br>Bonham, TX | 9.7[e] (32) | 0.53[e] (1.74) | Ambient | 1.9 (3,900) | 8.9 (29.5)[e] |

[a] Inside area of stack is 0.051 $m^2$ (0.55 $ft^2$).

[b] Inside area of stack is 0.016 $m^2$ (0.176 $ft^2$).

[c] Inside area of stack is 0.018 $m^2$ (0.196 $ft^2$).

[d] References - 11, 12, 14, 29, 31, 32, 33, 35, 36.

[e] Estimated from data on the rest of the industry.

arsenic from arsenic chemical manufacturing. The Strategies and Air Standards Division (SASD) of EPA is using these data in an ongoing effort to estimate exposure to arsenic from this source category.

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# APPENDIX A - BASES FOR THE CALCULATION OF ARSENIC EMISSIONS ESTIMATES

The purpose of this appendix is to present the methodologies, assumptions, and supporting data used to calculate arsenic emissions estimates for the source categories. The appendix has been organized to correspond with the arrangement and order of the individual source category chapters in the report. For example, information on emissions estimates from copper smelting, which is Chapter 3 in the report, would be found in Appendix A-3.

# APPENDIX A-3

## 1. Estimation of Primary Copper Smelting Process Arsenic Emissions Under Existing, Baseline, and EBC Levels of Control

### A. Existing Emissions

Estimates of process arsenic emissions from the primary copper smelters in their existing condition were taken directly from the arsenic material balances presented in reference 1.

### B. Baseline Emissions

In those cases for which the baseline configuration of the smelter varies from the existing configuration, original estimates of the baseline arsenic emissions from the smelters were made. The estimates were based on the arsenic distributions presented in reference 1. For example, consider the Kennecott/Hurley smelter. At present the plant has the configuration:

Reverberatory Furnace/ESP → Converter/Acid Plant.

As a result of the regulatory baseline Kennecott/Hurley will be replacing its reverberatory furnace with a flash furnace, which will allow the plant to install additional acid plant capacity to control $SO_2$ emissions from the smelting furnace step. The baseline configuration of the Kennecott/Hurley facility will then be identical to the existing configuration of the Phelps Dodge/Hidalgo facility (Flash Furnace → Converter/Acid Plant), for which arsenic emissions estimates are available. The assumption is made that for identical process and pollution control configurations, process arsenic emissions would be proportional to the arsenic content of the smelter feed. Therefore,

$$\begin{bmatrix}\text{estimated process arsenic}\\ \text{emissions from Kennecott/}\\ \text{Hurley under the regula-}\\ \text{tory baseline}\end{bmatrix} = \begin{bmatrix}\text{estimated process arsenic}\\ \text{emissions from Phelps Dodge/}\\ \text{Hidalgo under existing}\\ \text{conditions}\end{bmatrix} \times \begin{bmatrix}\dfrac{\begin{array}{c}\text{arsenic content of feed}\\ \text{materials to Kennecott/Hurley}\\ \text{per unit time}\end{array}}{\begin{array}{l}\text{arsenic content of feed}\\ \text{materials to Phelps Dodge/}\\ \text{Hidalgo per unit time}\end{array}}\end{bmatrix}$$

The estimated process arsenic emissions from the Phelps Dodge/Hidalgo smelter are taken from the arsenic distributions presented in reference 1, and the arsenic content of the feed materials to the Phelps Dodge/Hidalgo and Kennecott/Hurley smelters are taken from Table 3-2 of Chapter 3:

$$\begin{bmatrix}\text{estimated process arsenic}\\ \text{emissions from Kennecott/}\\ \text{Hurley under the regula-}\\ \text{tory baseline}\end{bmatrix} = 0.3\ \frac{\text{kg}}{\text{hr}} \times \frac{0.2\ \text{kg/hr}}{20\ \text{kg/hr}}$$

$$= 0.003\ \text{kg/hr} = 0.007\ \text{lb/hr}$$

## C. EBC Emissions

In all but three cases, one of the approaches in (1.A) or (1.B) was used to generate EBC arsenic emissions estimates. A different approach was needed for estimating EBC emissions from Kennecott/Hayden, Magma/San Manuel, and White Pines/Michigan. For these smelters, neither the existing nor baseline process emission control systems are equivalent to EBC for arsenic. New arsenic emissions estimates were made to assess the improved arsenic removal capabilities of the existing particulate removal equipment after the addition of spray chamber gas cooling systems. These estimates were made by modifying the arsenic distributions in reference 1 using the following assumptions:

(1) Uncontrolled arsenic emissions from a given process source follow the same pattern before and after implementation of the new control equipment. For example, the fractional volatilization and slagging in the converter expressed as a fraction of the arsenic input to the converter is assumed to remain fixed.

(2) Captured flue dusts that are presently recycled to the smelting process can continue to be recycled to the process regardless of the additional magnitude.

For example, consider the Kennecott/Hayden facility. The arsenic distribution estimates presented in reference 1 and shown in Figure 1 indicate that:

(1) 89 percent of the arsenic in the feed to the roaster is volatilized, and 11 percent remains in the calcined product. Dust captured by the cyclone in the roaster/AP train is recycled to the reverberatory furnace feed. The cyclone removes 83 percent of the arsenic in its feed. Sludge produced by the scrubber in the roaster/AP train is recycled to the roaster feed. The scrubber sludge contains 98 percent of the arsenic in the scrubber feed.

(2) 37 percent of the arsenic in the feed to the reverberatory furnace is volatilized, 15 percent is slagged, and 49 percent remains in the matte. Dust captured by the hot ESP is recycled to the reverberatory furnace feed. The ESP has an estimated arsenic collection efficiency of $\eta = 0.4$ at its current temperature of operation (650°F).

(3) 70 percent of the arsenic in the feed to the converter is volatilized, 29 percent is slagged, and 1 percent remains in the blister copper product. Dust captured by the ESP in the converter/AP train is recycled to the reverberatory furnace feed. The ESP removes 40 percent of the arsenic in its feed. Sludge produced by the scrubber in the converter/AP train is recycled to the roaster feed. The scrubber sludge contains 90 percent of the arsenic in the scrubber feed.

The basis of the estimate approach is to develop a material balance for the smelter using the above information.

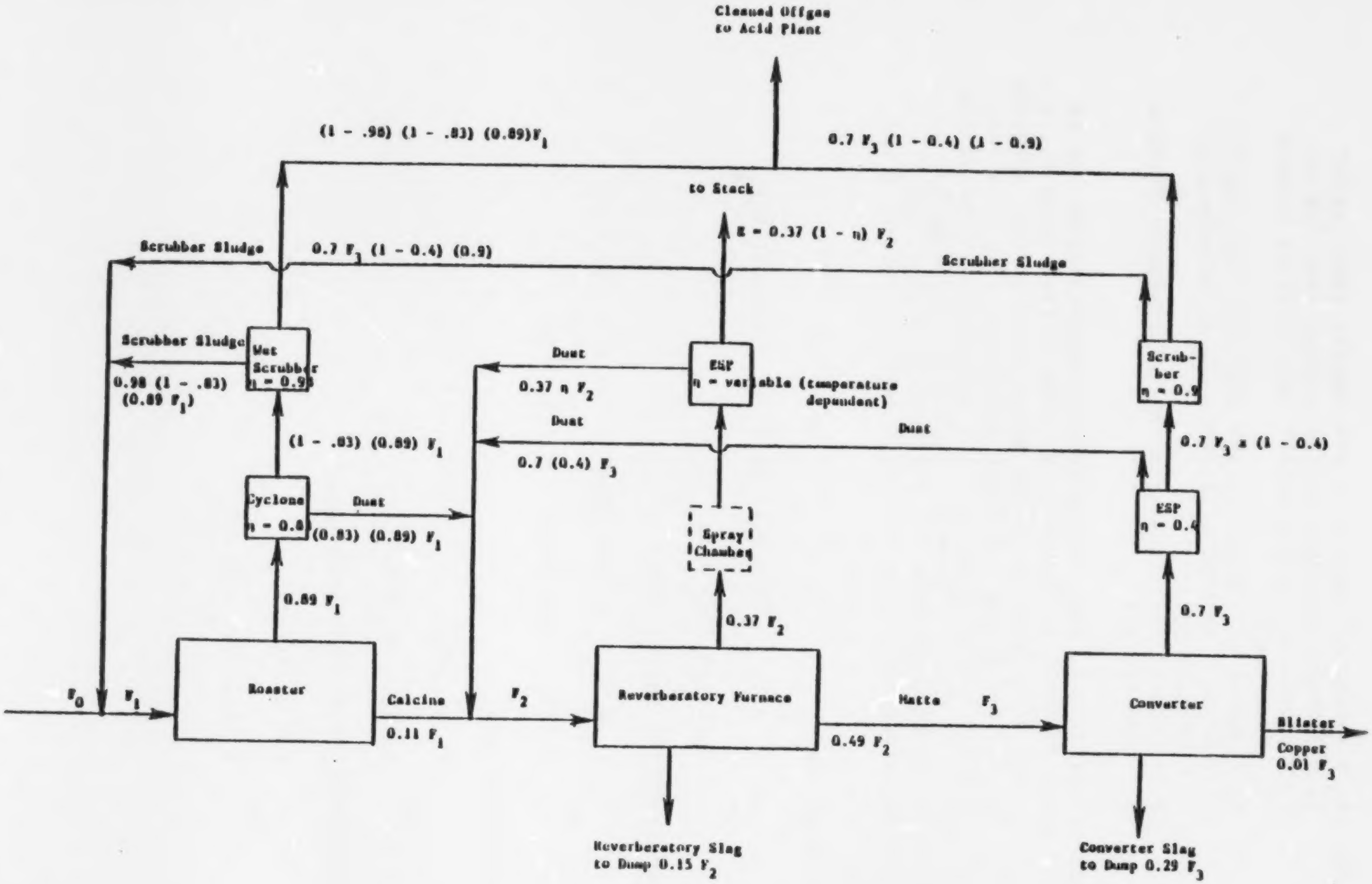

Cleaned Offgas to Acid Plant
(1 - .98) (1 - .83) (0.89)F1
0.7 F3 (1 - 0.4) (1 - 0.9)
to Stack
E = 0.37 (1 - n) F2
Scrubber Sludge
0.7 F3 (1 - 0.4) (0.9)
Scrubber Sludge
Scrubber Sludge
Wet Scrubber n = 0.98
0.98 (1 - .83) (0.89 F1)
Dust
ESP n = variable (temperature dependent)
Scrub-ber n = 0.9
0.37 n F2
Dust
Dust
(1 - .83) (0.89) F1
0.7 (0.4) F3
0.7 F3 x (1 - 0.4)
Cyclone n = 0.83
Dust
(0.83) (0.89) F1
Spray Chamber
ESP n = 0.4
0.89 F1
0.37 F2
0.7 F3
F0
F1
Roaster
Calcine
0.11 F1
F2
Reverberatory Furnace
Matte
F3
0.49 F2
Converter
Blister Copper 0.01 F3
Reverberatory Slag to Dump 0.15 F2
Converter Slag to Dump 0.29 F3

Figure 1. Arsenic distribution at the Kennecott/Hayden Copper Smelter.

Let: $F_0$ = amount of arsenic in the smelter feed (kg/hr)
$F_1$ = amount of arsenic in the roaster feed (kg/hr)
$F_2$ = amount of arsenic in the reverberatory furnace feed (kg/hr)
$F_3$ = amount of arsenic in the converter feed (kg/hr)
$\eta$ = arsenic removal efficiency of the reverberatory furnace ESP
E = arsenic emissions from the reverberatory furnace ESP (kg/hr)

All of the offgas, dust, and scrubber sludge streams can be expressed as shown in Figure 1 in terms of feed rates $F_0$, $F_1$, $F_2$, $F_3$, and efficiency $\eta$. There are a total of four unknowns ($F_1$, $F_2$, $F_3$, and E) and two known parameters ($F_0$, $\eta$). Four equations are needed to express the unknowns in terms of the parameters $F_0$ and $\eta$. These are provided by writing a material balance equation for the feed to each of the smelting processes and by writing a relation between E and $F_2$.

Roaster feed:

$$F_1 = F_0 + .89(1-83)(.98)F_1 + .7(1-.40)(.9)F_3$$

or

$$0.85F_1-0.38F_3 = F_0$$

Reverberatory Furnace Feed:

$$F_2 = .11F_1 + .89(.83)F_1 + .37\eta F_2 + .7(.4)F_3$$

or

$$0.85F_1 - (1-.37\eta)F_2 + 0.28F_3 = 0$$

Converter Feed:

$$F_3 = .49F_2$$

or

$$0.49F_2 - F_3 = 0$$

Reverberatory Furnace Emissions:

$$E = 0.37(1-\eta)F_2$$

or

$$0.37(1-\eta)F_2 - E = 0$$

The system of equations to be solved is:

(i) $0.85F_1 - 0.38F_3 = F_0$
(ii) $0.85F_1 - (1-.37\eta)F_2 + 0.28F_3 = 0$
(iii) $0.49F_2 - F_3 = 0$
(iv) $0.37(1-\eta)F_2 - E = 0$

Simultaneous solution of the four equations for the reverberatory furnace arsenic emissions E yields:

$$\begin{pmatrix} E_{\text{reverb}} \\ \text{ESP} \end{pmatrix} = (1 - \eta)\, F_0/(1.86 - \eta)$$

Similarly, it can be shown:

$$F_1 = (1 - .426\eta)\, F_0/(.672 - .364\eta)$$

$$F_2 = F_0/(.679 - .383\eta)$$

$$F_3 = F_0/(1.39 - .752\eta)$$

The feed to the acid plant circuit can also be expressed in terms of $F_1$ and $F_3$.

$$\begin{pmatrix} F_{\text{acid}} \\ \text{plant} \end{pmatrix} = .89\ (1-.83)\ (1-.98)\ F_1 + .7\ (1-.4)\ (1-.9)\ F_3$$

or

$$\begin{pmatrix} F_{\text{acid}} \\ \text{plant} \end{pmatrix} = 0.003\ F_1 + 0.042\ F_3$$

Using these equations, the arsenic distribution at Kennecott/Hayden can be computed provided $F_0$ and $\eta$ are known. From Table 3-2 of Chapter 3, $F_0$ = 8.5 kg/hr = 18.7 lb/hr. The reverb ESP collection efficiency $\eta$ depends on the temperature at which the device is operated. The available data suggest that a spray chamber/ESP system should be capable of achieving 96 percent arsenic collection efficiency. Using $\eta = .96$ and $F_0$ = 8.5 kg/hr = 18.7 lb/hr, it follows that

$$\begin{pmatrix} E_{\text{reverb}} \\ \text{ESP} \end{pmatrix}_{\text{EBC}} = 0.38 \text{ kg/hr} = 0.84 \text{ lb/hr}$$

Under existing and baseline control $\eta = 0.40$, so that

$$\left(E_{\substack{\text{reverb}\\ \text{ESP}}}\right)_{\text{baseline}} = 3.5 \text{ kg/hr} = 7.7 \text{ lb/hr}$$

Thus, the algebraic model predicts an achievable emissions reduction of 3.5 - .38 = 3.1 kg/hr = 6.8 lb/hr from the reverberatory furnace ESP. The amount of arsenic eliminated as slag increases, as does the amount of arsenic entering the acid plant unit.

2. Estimation of Primary Copper Smelting Fugitive Arsenic Emissions Under Baseline and Existing Levels of Control

A. Baseline Emissions

Estimates of baseline fugitive arsenic emissions from the primary copper smelters were taken directly from reference 1, except for the Cities Services plant in Copperhill, Tennessee for which fugitive arsenic emissions estimates were not given. For this plant, the approximate fugitive arsenic emissions distribution shown in Table 3-3 of Chapter 3 is used to generate baseline (uncontrolled) arsenic emissions estimates. From Table 3-2 of Chapter 3, the arsenic content of the feed material at the Copperhill plant is found to be 0.05 kg/hr $(0.1 \, \frac{\text{lb}}{\text{hr}})$. The fugitive arsenic emissions estimate from an arbitrary source S within the plant is generated as follows:

$$\begin{bmatrix}\text{fugitive arsenic}\\ \text{emissions from}\\ \text{source S}\end{bmatrix} = \begin{bmatrix}\text{amount of arsenic}\\ \text{in the feed material}\\ \text{to the plant per unit}\\ \text{as shown in Table 3-2}\end{bmatrix} \times \begin{bmatrix}\text{fraction of input arsenic}\\ \text{released as fugitive emissions}\\ \text{from source S as shown in}\\ \text{Table 3-3 of Chapter 3}\end{bmatrix}$$

For example, Table 3-3 of Chapter 3 indicates that 1.8 percent of the arsenic entering a typical copper smelter is released as fugitive emissions from the converter. Thus, the uncontrolled converter fugitive arsenic emissions at the Copperhill Plant are estimated as follows:

$$\begin{bmatrix}\text{uncontrolled fugitive arsenic}\\ \text{emissions from the converter}\\ \text{at Cities Services/Copperhill}\end{bmatrix} \begin{aligned} &= 0.05\ \text{kg/hr} \times 0.018 \\ &= 9 \times 10^{-4}\ \text{kg/hr} = 2 \times 10^{-3}\ \text{lb/hr}\end{aligned}$$

Similarly, it follows:

$$\begin{bmatrix}\text{Uncontrolled fugitive}\\ \text{arsenic emissions from}\\ \text{the matte and slag}\\ \text{tapping operations at}\\ \text{Cities Services/Copperhill}\end{bmatrix} \begin{aligned} &= 0.05\ \text{kg/hr} \times (.0034 + .0001) \\ &= 1.8 \times 10^{-4}\ \text{kg/hr} = \\ &\quad 3.9 \times 10^{-4}\ \text{lb/hr}\end{aligned}$$

## B. EBC Emissions

Estimates of EBC fugitive arsenic emissions from the primary copper smelters were obtained by applying the following assumed EBC capture and collection efficiencies to the baseline (uncontrolled) fugitive emissions estimates obtained above:

- for furnace tapping operations, 90 percent capture efficiency is assumed for the EBC ventilation system and 96 percent arsenic collection efficiency is assumed for the EBC fabric filter collection system. The overall control efficiency is:
  $\eta_{\text{overall}} = 0.90 \times 0.96 = 0.864$
- for converter operations, 95 percent capture efficiency is assumed for the EBC air curtain/secondary hood ventilation system and 96 percent collection efficiency is assumed for the EBC fabric filter collection efficiency. The overall control efficiency is:
  $\eta_{\text{overall}} = 0.95 \times 0.96 = .912$

The following equation was used to estimate EBC fugitive arsenic emissions for the two largest sources of fugitive arsenic emissions in the primary copper smelting industry:

$$\begin{bmatrix}\text{EBC fugitive}\\ \text{arsenic emissions}\\ \text{estimate for source S}\end{bmatrix} = \begin{bmatrix}\text{uncontrolled fugitive}\\ \text{arsenic emissions estimate}\\ \text{for source S}\end{bmatrix} \times \left[1 - \eta_{\text{overall}}\right]$$

For example, EBC fugitive arsenic emissions from the converter operation at Cities Services/Copperhill are estimated as follows:

$$\begin{aligned} \text{EBC Emissions} &= 9.0 \text{ x } 10^{-4} \text{ kg/hr x } (1 - .912) \\ &= 8 \text{ x } 10^{-5} \text{ kg/hr} = 1.7 \text{ x } 10^{-4} \text{ lb/hr} \end{aligned}$$

REFERENCES FOR APPENDIX A-3

1. U. S. Environmental Protection Agency. Preliminary Draft Report - National Emission Standard for Arsenic Emissions from Primary Copper Smelters. Research Triangle Park, N. C. EPA Contract No. 68-02-3060. 1979.

# APPENDIX A-4

## 1. Primary Lead Smelting Process Arsenic Emissions under Existing Level of Control

The methods used to obtain estimates of the process arsenic emissions for each of the five primary lead smelters are outlined below.

### A. ASARCO/East Helena

Process arsenic emissions from this smelter were taken from the test results[1] shown in Table 4-3 of Chapter 4. It was assumed that the offgas streams from Baghouses 1, 2, and 3 are vented to the blast furnace/reverberatory furnace stack.

### B. ASARCO/El Paso

#### (i) Blast furnace/Reverberatory furnace

Arsenic emission data from the blast furnace/reverberatory furnace stack were provided by ASARCO[2] (0.16 lb/hr, or 0.07 kg/hr).

#### (ii) Zinc fuming furnace

Arsenic emissions from the zinc fuming furnace were estimated by analogy to ASARCO/East Helena. The assumption is made that for comparable emission control systems, arsenic emissions from a particular plant component are proportional to the arsenic content of the feed material to the plant.

$$E_{\substack{\text{zinc fuming}\\ \text{furnace}}\text{(El Paso)}} = E_{\substack{\text{zinc fuming}\\ \text{furnace}}\text{(East Helena)}} \times \frac{\text{weight percent arsenic in feed}_{\text{(El Paso)}}}{\text{weight percent arsenic in feed}_{\text{(East Helena)}}} \times \frac{\text{smelter capacity}_{\text{(El Paso)}}}{\text{smelter capacity}_{\text{(East Helena)}}}$$

Since the two plants process western lead ore and since the capacities of the plants are identical (82,000 Mg/yr) it follows that the estimated arsenic emissions at ASARCO/El Paso are identical to the measured arsenic emissions at ASARCO/East Helena. Therefore

$$E_{\substack{\text{zinc fuming}\\ \text{furnace}\\ \text{(ASARCO/El Paso)}}} = E_{\substack{\text{zinc fuming}\\ \text{furnace}\\ \text{(ASARCO/East Helena)}}} = 0.2 \text{ kg/hr} = 0.4 \frac{\text{lb}}{\text{hr}}$$

(iii) Sinter/acid plant stack

ASARCO/El Paso sends its entire sinter machine offgas stream to an acid plant unit (100 percent gas recirculation). Arsenic emissions from the sinter/acid plant stack are assumed to be negligible in comparison to emissions from the other plant components.

C. AMAX/Boss

Emissions test data are not available for process arsenic emissions from this smelter. However, material balance information provided by AMAX[3] indicates that 12.9 percent of the arsenic entering the plant cannot be accounted for in the materials leaving the smelter. This amounts to 0.019 tons of arsenic per blast furnace day, or about 0.72 kg/hr (1.6 lb/hr). Thus, the total arsenic emissions from the plant (process + fugitive) are bounded from above by 0.72 kg/hr (1.6 lb/hr).

The "best estimate" of process arsenic emissions from the plant was obtained by analogy to ASARCO/East Helena. Emissions from the sinter machine, blast furnace, and reverberatory furnace were assumed proportional to the arsenic content of the feed at the two plants. The weight percent of the ore concentrate at AMAX is 0.02 percent and at ASARCO/East Helena, about 0.4 percent. The production capacities of the plants are 127,000 and 82,000 Mg/yr lead, respectively. Thus,

$$\begin{aligned} E_{\text{main}} &= \left(E_{\text{sinter}} + E_{\text{blast}} + E_{\text{reverb}}\right)_{\text{East Helena}} \\ &\quad \times \frac{0.02}{0.4} \times \frac{127{,}000}{82{,}000} \\ &= 0.2 \text{ kg/hr} = 0.4 \frac{\text{lb}}{\text{hr}} \end{aligned}$$

## D. St. Joe/Herculaneum

No process arsenic emissions data are available for St. Joe/Herculaneum. Estimates for total maximum arsenic emissions (process + fugitive) were obtained by analogy to AMAX/Boss. Estimates for process arsenic emissions were made by analogy to ASARCO/East Helena. The arsenic content of the ore concentrate smelted at St. Joe/Herculaneum is 0.02 weight percent. The production capacity of the St. Joe smelter is 204,000 Mg/yr lead.

$$E_{\substack{\text{process}\\ +\text{ fugitive (St. Joe)}}} = E_{\substack{\text{process}\\ +\text{ fugitive (AMAX)}}} \times \frac{.02}{.02} \times \frac{204{,}000}{127{,}000}$$

$$= 1.12 \text{ kg/hr} = 2.5 \frac{\text{lb}}{\text{hr}}$$

$$E_{\substack{\text{main}\\ \text{stack}\\ \text{(St. Joe)}}} = \left(E_{\text{sinter}} + E_{\text{blast}} + E_{\text{reverb}}\right)_{\substack{\text{East}\\ \text{Helena}}}$$

$$\times \frac{.02}{.4} \times \frac{204{,}000}{82{,}000}$$

$$= 0.3 \text{ kg/hr} = 0.7 \frac{\text{lb}}{\text{hr}}$$

## E. ASARCO/Glover

No process arsenic emissions data are available for ASARCO/Glover except for the venturi stack (0.0005 kg/hr, or 0.001 lbs/hr).[2] Estimates for total maximum arsenic emissions (process + fugitive) were obtained by analogy to AMAX/Boss. Estimates for process arsenic emissions were made by analogy to ASARCO/East Helena. The arsenic content of the ore smelted at the ASARCO/Glover smelter is 0.025 weight percent and the production capacity of the plant is 100,000 Mg/yr lead.

$$E_{\substack{\text{process}\\ +\text{ fugitive}}}\ \substack{\text{ASARCO/}\\ \text{Glover}} = E_{\substack{\text{process (AMAX)}\\ +\text{ fugitive}}} \times \frac{.025}{.02} \times \frac{100{,}000}{127{,}000}$$

$$= 0.55 \text{ kg/hr} = 1.2 \frac{\text{lb}}{\text{hr}}$$

$$E_{\text{main stack ASARCO/Glover}} = \left(E_{\text{sinter}} + E_{\text{blast}} + E_{\text{reverb}}\right)_{\text{East Helena}} \times \frac{0.025}{0.4} \times \frac{100{,}000}{82{,}000}$$

$$= 0.2 \text{ kg/hr} = 0.4 \ \frac{\text{lb}}{\text{hr}}$$

## 2. Primary Lead Smelting Fugitive Arsenic Emissions Under Existing Level of Control

Fugitive arsenic emissions data are available for ASARCO/East Helena and ASARCO/Glover[4] (Tables 4-4 and 4-5 of Chapter 4). Estimates of fugitive arsenic emissions at the other primary lead smelters were obtained by analogy to these two smelters. As in the case of process arsenic emissions, the fugitive arsenic emissions at a smelter were assumed to be proportional to the arsenic content of the feed material.

For example:

$$E_{\text{fugitive}}\left(\begin{matrix}\text{AMAX/}\\ \text{Boss}\end{matrix}\right) = E_{\text{fugitive}}\left(\begin{matrix}\text{ASARCO/}\\ \text{Glover}\end{matrix}\right) \times \frac{\text{wt \% of arsenic in feed to AMAX/Boss}}{\text{wt \% of arsenic in feed to ASARCO/Glover}}$$

$$\times \frac{\text{production capacity at AMAX/Boss}}{\text{production capacity at ASARCO/Glover}}$$

$$= 0.005 \ \frac{\text{kg}}{\text{hr}} \times \frac{0.02}{0.025} \times \frac{127{,}000}{100{,}000}$$

$$= 0.005 \ \frac{\text{kg}}{\text{hr}} = 0.011 \ \frac{\text{lb}}{\text{hr}}$$

## REFERENCES FOR APPENDIX A-4

1. U. S. Environmental Protection Agency. Emissions Measurement at the ASARCO Lead Smelter in East Helena, Montana. Research Triangle Park, N. C. EPA Contract No. 68-01-4140. May 1980.

2. Letter from Richardson, J. B., ASARCO, to Fensterheim, R. J., Chemical Manufacturers Association. May 17, 1982. ASARCO response to Radian Emission Estimates.

3. Letter from Kearney, W. M., AMAX Lead Company of Missouri, to Lee Beck, EPA:ISB. August 6, 1981. Arsenic material balance at the AMAX smelter.

4. U. S. Environmental Protection Agency. Sample Fugitive Lead Emissions from Two Primary Lead Smelters. Research Triangle Park, N. C. Publication No. EPA-450/3-77-031. October 1977.

# APPENDIX A-5

## 1. Estimation of Primary Zinc Smelting Arsenic Emissions Under Baseline and EBC Levels of Control

### A. Electrolytic Zinc Plants

The only source of significant arsenic emissions at an electrolytic zinc plant is the roaster acid plant tail gas. Fugitive arsenic emissions are assumed to be negligible from the fluid bed roasting systems. Two methods were used to estimate the acid plant tail gas arsenic emissions.

(i) The first method assumes that the tail gas leaves the acid plant stack with an arsenic content corresponding to saturated $As_4O_6$ vapor at 60°C (140°F). This is the typical temperature at which the offgas leaves the preliminary wet scrubber in the acid plant circuit. The assumption is made that the condensed arsenic is removed by the ESP mist precipitator that generally follows the scrubber. Regression of the $As_4O_6$ vapor pressure data presented in reference 1 over the temperature range $90 < T < 150°C$ $(194 < T < 302°F)$ yields the relation $\log_{10} P^* = 12.77 - 6067\ (1/T)$, where T = temperature in °K and $P^*$ = vapor pressure of $As_4O_6$ in mm Hg. Extrapolating the vapor pressure relation back to 333°K (60°C) yields $P^* = 3.57 \times 10^{-6}$ mm Hg @ 60°C. Assuming ideal gas behavior, this corresponds to an arsenic concentration of $5.7 \times 10^{-5}$ g As/Nm$^3$. The arsenic emissions estimates for the roaster acid plant tail gas streams are obtained as follows:

$$\begin{bmatrix}\text{Acid Plant}\\ \text{Emissions}\end{bmatrix} = \begin{bmatrix}\text{Volumetric Flow}\\ \text{Rate of the Tail}\\ \text{Gas Stream at}\\ \text{Standard Conditions}\end{bmatrix} \times 5.7 \times 10^{-5} \text{ g As/Nm}^3$$

For example, the volumetric flowrate for the acid plant offgas stream at ASARCO/Corpus Christi is 6.9 Nm$^3$/sec. Thus, the arsenic emissions estimate is:

$$6.9 \text{ Nm}^3\text{/sec} \times 5.7 \times 10^{-5} \text{ g As/Nm}^3 \times 3600 \text{ sec/hr}$$

$$= 1.4 \times 10^{-3} \text{ kg/hr} = 3.1 \times 10^{-3} \text{ lb/hr}$$

(ii) The second method assumes that the tail gas leaves the acid plant stack with the maximum allowable arsenic content for the inlet gas to the acid plant catalyst (1.2 mg/$Nm^3$). Thus, the emissions estimate is:

$$6.9\ Nm^3/sec \times 1.2 \times 10^{-6}\ kg/Nm^3 \times 3600\ sec/hr$$

$$= 3.0 \times 10^{-2}\ kg/hr = 6.6 \times 10^{-2}\ lb/hr$$

Since baseline and EBC control are equivalent for the electrolytic zinc plants, the EBC arsenic emissions estimates are identical to the baseline arsenic emissions estimates. In the text, the estimates made by method (i) are called the "best estimates" and the estimates made by method (ii) are called the "high estimates."

## B. St. Joe/Monaca Electrothermal Smelter

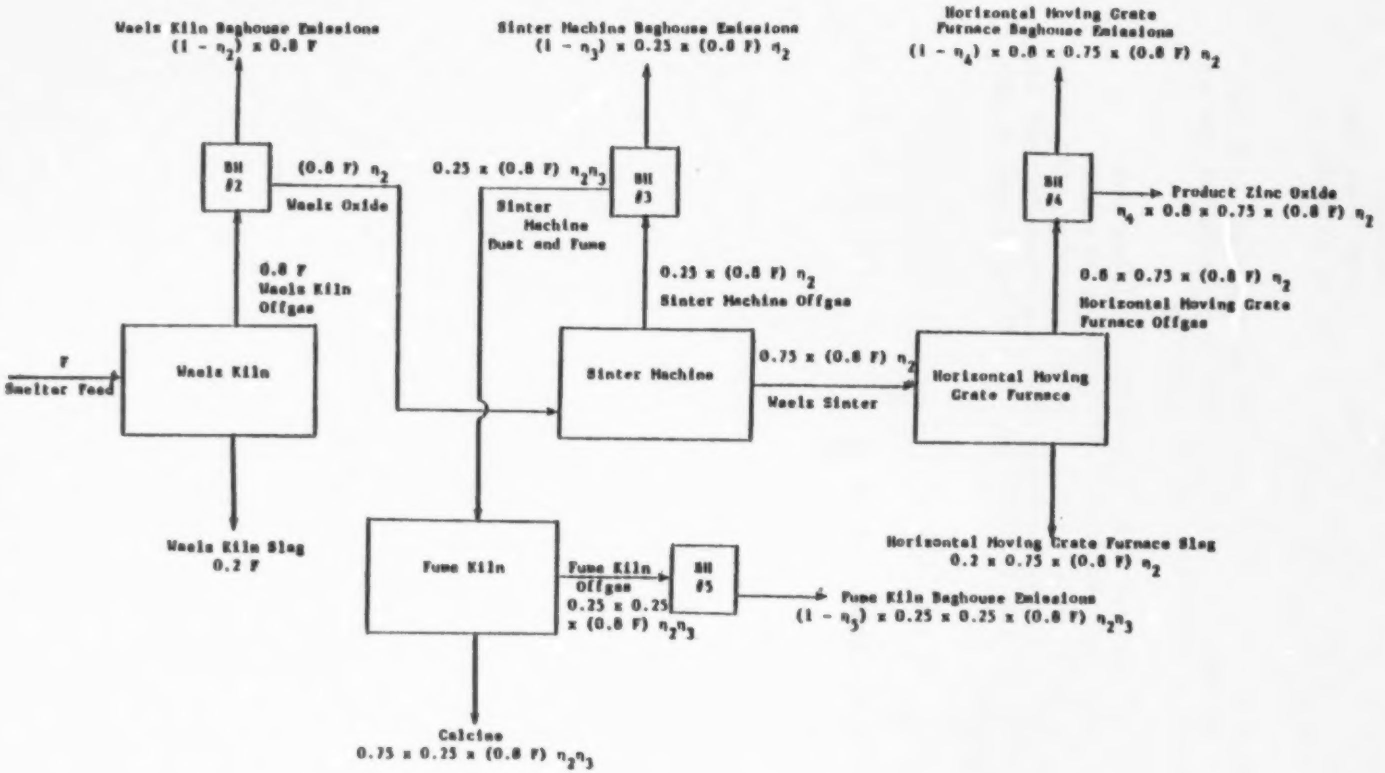
The arsenic emissions estimates for this plant were obtained by direct correspondence[2,3] with the plant management.

## C. New Jersey Zinc/Palmerton Zinc Oxide Plant

There is no available information concerning the distribution of arsenic at the New Jersey Zinc zinc oxide plant. Production information obtained from the plant indicates that about 1.2 kg As/hr is contained in the smelter feed.[4] There are five baghouses at the plant; two are "hot" baghouses (#1 @ 193°C and #2 @ 140°C) and three are "cool" baghouses (#3 @ 91°C, #4 @ 82°C, and #5 @ 82°C). Two slags are produced in the operation, one from the waelz kiln and one from the horizontal moving grate furnace. The following somewhat arbitrary assumptions are made to estimate the arsenic distribution at the plant (see Figure 1):

(i) Assume that 20 percent of the arsenic entering the waelz kiln is slagged and 80 percent is volatilized with the waelz oxide. Assume that arsenic emissions associated with the fugitive dust baghouse are negligible compared to those from the other sources. Assume that the 140°C baghouse serving the waelz kiln process offgas has an arsenic capture efficiency of 40 percent (by analogy to medium-temperature copper smelter particulate controls).

(ii) Assume that 25 percent of the arsenic in the sinter machine feed is volatilized (by analogy to a "typical" copper smelter roaster) and that the cool sinter machine baghouse has an arsenic capture efficiency of 96 percent.


Waelz Kiln Baghouse Emissions
(1 - η2) x 0.8 F
Sinter Machine Baghouse Emissions
(1 - η3) x 0.25 x (0.8 F) η2
Horizontal Moving Grate
Furnace Baghouse Emissions
(1 - η4) x 0.8 x 0.75 x (0.8 F) η2
BH #2
(0.8 F) η2
Waelz Oxide
0.25 x (0.8 F) η2η3
BH #3
Sinter
Machine
Dust and Fume
BH #4
Product Zinc Oxide
η4 x 0.8 x 0.75 x (0.8 F) η2
0.8 F
Waelz Kiln
Offgas
0.25 x (0.8 F) η2
Sinter Machine Offgas
0.8 x 0.75 x (0.8 F) η2
Horizontal Moving Grate
Furnace Offgas
F
Smelter Feed
Waelz Kiln
Sinter Machine
0.75 x (0.8 F) η2
Waelz Sinter
Horizontal Moving
Grate Furnace
Waelz Kiln Slag
0.2 F
Fume Kiln
Fume Kiln
Offgas
0.25 x 0.25
x (0.8 F) η2η3
BH #5
Fume Kiln Baghouse Emissions
(1 - η3) x 0.25 x 0.25 x (0.8 F) η2η3
Horizontal Moving Grate Furnace Slag
0.2 x 0.75 x (0.8 F) η2
Calcine
0.75 x 0.25 x (0.8 F) η2η3

**Existing Arsenic Emissions:**

$\eta_2 = 0.4$

$\eta_3 = \eta_4 = \eta_5 = 0.96$

F = 1.2 kg/hr arsenic

BH #2: E = (1 - 0.4) x 0.8 x 1.2 kg/hr = 0.58 kg/hr

BH #3: E = (1 - 0.96) x 0.25 x 0.8 x 1.2 kg/hr x 0.4 = 0.004 kg/hr

BH #4: E = (1 - 0.96) x 0.8 x 0.75 x 0.8 x 1.2 kg/hr x 0.4 = 0.009 kg/hr

BH #5: E = 0.25 x 0.25 x 0.8 x 1.2 kg/hr x 0.4 x 0.96 (1 - .96) = 0.001 kg/hr

**BAT Arsenic Emissions:**

$\eta_2 = \eta_3 = \eta_4 = \eta_5 = 0.96$

F = 1.2 kg/hr arsenic

BH #2: E = (1 - 0.96) x 0.8 x 1.2 kg/hr = 0.04 kg/hr

BH #3: E = (1 - 0.96) x 0.25 x 1.2 kg/hr x 0.96 = 0.01 kg/hr

BH #4: E = (1 - 0.96) x 0.8 x 0.75 x 0.8 x 1.2 kg/hr x 0.96 = 0.02 kg/hr

BH #5: E = 0.25 x 0.25 x 0.8 x 1.2 kg/hr x 0.96 x 0.96 x (1 - .96) = 0.002 kg/hr

Figure 1. Estimated arsenic distribution at the New Jersey Zinc ZnO Smelter.

(iii) Assume that 20 percent of the arsenic entering the horizontal grate furnace is slagged and 80 percent volatilizes with the product ZnO vapor. Assume that the cool horizontal grate furnace baghouse has an arsenic collection efficiency of 96 percent.

(iv) Assume 25 percent of the arsenic entering the fume kiln is volatilized. Assume that the cool fume kiln baghouse has an arsenic collection efficiency of 96 percent.

Using this set of assumptions, a material balance was prepared to assess the "best estimate" of existing arsenic emissions. They are shown on Figure 1. Then, assuming that added spray chamber capacity is added to waelz kiln baghouse so that the temperature is lowered to about 100°C and $\eta_2 = 0.96$, a set of EBC emissions are estimated.

Existing As emissions: $0.6 \text{ kg/hr} = 1.3 \frac{\text{lb}}{\text{hr}}$

EBC As emissions: $0.07 \text{ kg/hr} = 0.15 \frac{\text{lb}}{\text{hr}}$

## REFERENCES FOR APPENDIX A-5

1. U. S. Environmental Protection Agency. Arsenic Emissions from Primary Copper Smelters - Background Information for Proposed Standards. Preliminary Draft. Research Triangle Park, N. C. February 1981.

2. Telecon. Janeck, T., St. Joe Minerals Corporation, with Keller, L., Radian Corporation. February 11, 1982. Information concerning the St. Joe Minerals zinc smelter in Monaca, Pennsylvania.

3. Letter from Janeck, T., St. Joe Minerals Corporation, to Keller, L., Radian Corporation. March 10, 1982. Arsenic Emissions from the St. Joe/Monaca zinc smelter.

4. Telecon. Silvestris, M., New Jersey Zinc Co., with Keller, L., Radian Corporation.

## APPENDIX A-6

### 1. Calculation of Arsenic Emissions from Secondary Lead Smelters

Approach

Particulate emissions and typical lead concentrations of particulates are well documented. Arsenic and lead have been shown to behave similarly in studies of trace element emissions from coal-fired power plants. In addition, lead/arsenic ratios of dustfall around secondary lead smelters have been measured. By using these ratios in conjunction with particulate and lead emission rates one can estimate an arsenic emission rate.

1. Particulate Emissions from Secondary Lead Smelters.

All furnaces are equipped with fabric filters. Fabric filters are capable of lowering emissions to below 50 $mg/m^3$ (0.022 gr/dscf) NSPS limit. Most test results are below this (see Table 1). For estimation assume particulate emissions are .022 gr/dscf.

2. Lead Content of Particulate.

Measurements of the lead contents of particulate emissions from secondary lead smelters show wide variations. In general, the lead contents increase with decreasing particle size. Table 1 shows average lead contents to vary from 1.5 to 47 percent. General Battery test data[1] show a range of 20 - 52 percent with a weighted average of 42 percent. This lead content will be used in this study.

3. Lead/Arsenic Ratios of Two Secondary Smelters.

From Reference 2, page 319, Table 5, we have the following average arsenic and lead contents in soil and foliage (ppm by weight).

TABLE 1. EMISSIONS TEST RESULTS FOR SECONDARY LEAD SMELTERS

| PLANT | SOURCE | CONTROL DEVICE | TEMPERATURE °F | PARTICULATE gr/dscf | LEAD gr/dscf | Lead conc. in particulate |
|---|---|---|---|---|---|---|
| Sanders[6] Lead | Blast Furnace | AB/Fabric Filter | - | .0002 | - | |
| Tonolli[7] | Rotary Furnace | AB/Fabric Filter | 87° | .00616 | .00013 | 2% |
| (FF & Scrubber in Series) | | Scrubber | - | .01264 | .00024 | 1.9 |
| | | AB/FF/ Scrubber | - | .024<br>.020 | .00018<br>.00007 | 0<br>0 |
| General[8] Battery | | AB/FF/ Scrubber | 96° | .01 | .00014 - .00025 | 0 |
| A[9] | Blast Furnace | AB/Fabric Filter | 178° | .0026 | .00034 | 13 |
| B | Blast Furnace | AB/FF/ Scrubber | 121° | .0079 | .00012 | 1.5 |
| C | Blast Furnace | Scrubber | 95° | .0143 | .00105 | 7 |
| D | Blast Furnace | AB/Fabric Filter | 152° | .0013 | .00061 | 47 |
| E | Blast Furnace | AB/Fabric Filter | 175° | .0059 | - | |
| F | Blast Furnace | AB/Fabric Filter | 110° | .0142 | - | |
| G | Reverb Furnace | Fabric Filter | 168° | .0035 | .00061 | 17 |
| H | Reverb Furnace | Fabric Filter | 124° | .0033 | .00038 | 12 |
| I | Reverb Furnace | Fabric Filter | 327° | .0022 | - | 734,100 |
| AVERAGE FABRIC FILTER | | | 176° | .0043 | .000414 | |
| AVERAGE FF/SCRUBBER | | | 101° | .010 | .00017 | |

| | Pb | As | Ratio Pb/As |
|---|---|---|---|
| Smelter A | | | |
| Foliage | 173 | 7.4 | 23:1 |
| Soil | 3,106 | 107.2 | 28.9:1 |
| Smelter B | | | |
| Foliage | 160 | 2.4 | 66:1 |
| Soil | 3,292 | 34.8 | 95:1 |
| Urban Control Area | | | |
| Foliage | 91 | 0.9 | 101:1 |
| Soil | 542 | 9.8 | 55:1 |
| A-Urban | | | |
| Foliage | 173 - 91 | 7.4 - .9 | 12.6:1 |
| Soil | 3,106 - 542 | 107.2 - 9.8 | 26.3:1 |
| B-Urban | | | |
| Foliage | 160 - 91 | 2.4 - .9 | 99.3:1 |
| Soil | 3,292 - 542 | 36.8 - 9.8 | 110:1 |

The range of ratios seen is 12.6:1 to 110:1.

For the purpose of this study we will use 13:1 to maximize arsenic concentrations. The single flue dust analysis identified during this study shows an arsenic content of 0.3 percent arsenic in the material captured by a fabric filter. Using a lead content of 42 percent and a 13:1 Pb/As ratio, the arsenic in the material escaping is approximately 3.2 percent As. (This would be .38 percent @ 110:1.) This represents an enrichment ratio of ≅ 11 from the larger to the smaller particulate. A similar enrichment can be seen between the .1 - 3 μm particulate and the 27 - 76 μm particulate in Table 2.

4. Emissions Estimates

a. Process Emissions

Using the model plant flow rates proposed by MRI[3], arsenic emissions from a typical furnace can now be estimated. For the model plants we have the following:

| Plant Size | Small | Medium | Large |
|---|---|---|---|
| Flow rate dscfm | 20,000 | 36,000 | 72,000 |
| Hours of operation | 6,000 | 6,000 | 6,000 |
| Lead production tpy | 10,000 | 20,000 | 40,000 |
| Hourly | 1.67 | | |

## DEVICE PERFORMANCE FOR ARSENIC AND LEAD EMISSIONS FROM COAL-FIRED POWER PLANTS

ENRICHMENT RATIOS[10]

| Element | Fly ash |  |  |  | Ratios |  |  |
|---|---|---|---|---|---|---|---|
|  | 0.1 - 3.0 μm (A) | 22 - 74 μm (B) | Bulk (C) | Coal (D) | A/B | A/D | C/D |
| Arsenic | 71 | 6.4 | 17 | 1.4 | 11 | 51 | 12 |
| Lead | 79 | 12 | 20 | 1.6 | 6.6 | 49 | 12 |

### ELECTROSTATIC PRECIPITATOR AND SCRUBBER PERFORMANCE ON TRACE ELEMENTS

ELECTROSTATIC PRECIPITATOR[11]

|  | Particulate | Arsenic |  | Lead |  |
|---|---|---|---|---|---|
|  |  | μg/g | mg/min. | μg/g | mg/min. |
| Inlet | 4.6 kg/min. | 130 | 598 | 110 | 506 |
| Outlet | 3.0 kg/min. | 150 | 450 | 130 | 390 |
| Efficiency % | 35 | --- | 25 | --- | 23 |

SCRUBBER[19]

|  | Particulate | Arsenic |  | Lead |  |
|---|---|---|---|---|---|
|  |  | μg/g | mg/min. | μg/g | mg/min. |
| Inlet | 4.2 kg/min. | 130 | 546 | 110 | 462 |
| Outlet | 0.34 kg/min. | 280 | 95.2 | 340 | 115.6 |
| Efficiency % | 92 | --- | 83 | --- | 75 |

ELECTROSTATIC PRECIPITATOR[12]

|  | Arsenic g/min. |  | Lead g/min. |  |
|---|---|---|---|---|
|  | 1972 | 1973 | 1972 | 1973 |
| Inlet | 1.8 | 8.1 | 7.8 | 5.9 |
| Outlet | .2 | .2 | .2 | .2 |
| Efficiency % | 88 | 97 | 97.4 | 96.6 |

Use the largest flow per ton of product (i.e., the small plant assumptions). Hourly arsenic emissions are:

$$20{,}000 \text{ dscfm} \times \frac{.022 \text{ grdscf}}{7{,}000 \text{ gr/lb}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{.032 \text{ lb As}}{\text{lb particulate}}$$

hourly As = .12 lb/hr

Emission factor for a small plant lb/ton lead $= \frac{.12 \text{ lb/hr}}{1.67 \text{ tons/hr}} =$ .072 lb As/ton lead

Using the ratios of flowrates we can estimate emissions from other sites.

For a medium plant emissions $= \frac{36{,}000}{20{,}000} \times .12 \text{ lb/hr} = .21 \text{ lb/hr}$

For a large plant emissions $= \frac{72{,}000}{20{,}000} \times .12 = .43 \text{ lb/hr}$

b. Process Fugitive Emissions

Process fugitives include charge preparation, slag tapping and metal pouring emissions. These are currently controlled at all secondary lead smelters. There have been two studies of fugitive lead emissions which measured process fugitives. These are: The General Battery Fugitive Emissions Study[1] and the East Penn Emissions and Emissions Control Study[4]. The General Battery Study showed the following:

| Source | Lead Emissions | Ratio to Process |
|---|---|---|
| Process Controlled by Fabric Filters | 750 | 1:1 |
| Ventilation (sanitary) Fabric Filters | 558 | 0.74:1 |
| Area Fugitives | 1,270 | 1.7:1 |

The East Penn Study showed the following:

| Source | Flow Rate $m^3$/h | Lead Content<br>Conc. mg/$m^3$ | <br>wt gms/h | Ratio to Process |
|---|---|---|---|---|
| Process Controlled by Fabric Filters | 33,000 | 6 | 198 | 1:1 |
| Slag Tap Fabric Filter | 8,400 | 1.4 | 11.76 | |
| Sanitary Fabric Filter | 59,000 | 1.5 | 88.5 | |
| | Total Process Fugitive | | 100.26 | 0.5:1 |

Choosing the worst case, assume controlled process fugitive emissions are 74 percent of controlled process emissions.

The MRI report[5] presents an estimate of uncontrolled process fugitive emissions on page 14. They give 326 tpy of total particulate for 10,000 tpy of lead. Using our assumptions for the arsenic content of the particulate yields an uncontrolled arsenic emissions rate of

$$\frac{326 \text{ tpy Particulate}}{10{,}000 \text{ tpy lead}} \times \frac{.032 \text{ ton As}}{\text{ton particulate}} = .00104 \text{ t As/t lead}$$

Assuming the fabric filter is 99 percent efficient the equivalent controlled rate would be .0000104 t/t. The estimate using the .74 of process is $.072 \text{ lb/ton} \times \frac{1 \text{ ton}}{2{,}000 \text{ lbs}} \times .74 = .000027 \text{ t/t}$.
These estimates are in fairly close agreement. Use the larger of the two to be conservative.

c. Area Fugitives

Use the General Battery data. Area fugitives are 1.7 x controlled process emissions. These emissions correspond to a typical level of control. Emissions would be lowered when the SIPs are revised to allow compliance with the lead NAAQS. Since ambient lead measurements are not available for all smelter locations, no estimates can be made of the emissions reduction would occur when compliance is achieved.

Area fugitives for a small plant:

Arsenic emissions = 1.7 x .072 = .12 lb/ton
lb/ton

5. EBC Emissions Estimates for Process Sources

Table 1 presents lead and particulate emissions test data for blast and reverberatory furnaces controlled by fabric filters and scrubbers. The table shows that a fabric filter/scrubber combination operates at a lower exit gas temperature than a fabric filter alone and has lower lead emissions. The incremental reduction in lead emissions attributable to the combination is 59 percent. Lead and arsenic particulate are controlled to approximately the same efficiency by other control devices (Table 2). Therefore, assume arsenic removal efficiency = lead removal efficiency. Arsenic emission factors for EBC = .59 x existing.

APPENDIX A-6

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# APPENDIX A-7

## 1. Calculation of Total Arsenic Applied Versus the Amount of Total Arsenic Found in Gin Trash

The purpose of calculation No. 1 is to compare or check the arsenic emission estimates that can be made by using either arsenic acid application data or gin trash arsenic content data. Approximately equivalent emissions estimates by using both methods indicates that the data associated with both techniques is fairly reliable.

### I. Determination of Total Arsenic Applied

#### A. Assumptions

1. Application efficiency = 5% (Section 7.1.3.5)
2. Total hectares affected = 850,000 (Section 7.1.1)
3. Arsenic acid application rate = 4.9 kg/ha (Section 7.1.2)
4. The ratio of elemental arsenic in arsenic acid ($H_3AsO_4$) is 0.52.

#### B. Calculations

1. (850,000 ha) x (4.9 kg/ha) = $4.17 \times 10^6$ kg
2. ($4.17 \times 10^6$) x 0.05 = $2.09 \times 10^5$ kg of total arsenic acid on the plants
3. ($2.09 \times 10^5$ kg) x 0.52 = $1.09 \times 10^5$ kg of total elemental arsenic on the plants

### II. Determination of Total Arsenic in Gin Trash

#### A. Assumptions

1. 334 kg lint cotton per hectare of seed cotton harvested (Chapter 7, ref. 8)
2. 385.6 kg trash per bale of lint cotton (Section 7.1.6.1)
3. Total arsenic in trash = 225 ppm (Section 7.1.4)

#### B. Calculations

1. 334 kg lint/ha ÷ 226.8 kg lint/bale = 1.47 bales/ha
2. 1.47 bales/ha x (850,000 ha) = $1.25 \times 10^6$ bales

3. $(1.25 \times 10^6$ bales$) \times 385.6$ kg/bale $= 4.82 \times 10^8$ kg trash
4. $(4.82 \times 10^8$ kg trash$) \times 0.000225 = 1.08 \times 10^5$ kg of total elemental arsenic in the gin trash

## III. Conclusion

Considering the inaccuracies that are part of the estimating process, the two methods of determining arsenic emissions are fairly equivalent. The two answers, $1.08 \times 10^5$ and $1.09 \times 10^5$, represent a difference in the estimating techniques of less than 1 percent.

## 2. Example Calculation on Cotton Gin Model Plant Process Emissions

### A. Assumptions

1. Total arsenic content of gin trash = 225 ppm (Section 7.1.4)
2. 99 percent of trash ≥ 74 microns (Section 7.2.2.1)
3. Trash greater than 30 microns removed at 99 percent efficiency (Section 7.2.2.1)
4. Trash smaller than 30 microns removed at 40 percent efficiency (Section 7.2.2.2)
5. High pressure section emissions constitute 46.4 percent of total gin emissions (Chapter 7, ref. 40)
6. 4 bale/hr model will be used as the example, total trash input to the gin = 385.6 kg/bale or 1542 kg/hr
7. The 7, 12, and 20 bale/hr estimates were calculated using same assumptions except the trash input rate changes.

### B. Calculations

1. 1542 kg/hr x 0.99 = 1527 kg/hr above 74 microns
   1542 kg/hr - 1527 kg/hr = 15 kg/hr below 74 microns
2. 1527 kg/hr x 0.01 = 15.27 kg/hr emitted particulate
   15 kg/hr x 0.60 = 9 kg/hr emitted particulate
3. 15.27 kg/hr + 9 kg/hr = 24.27 kg/hr emitted particulate from total gin
4. 24.27 kg/hr x 0.464 = 11.26 kg/hr emitted particulate from high pressure section of gin
5. 11.26 kg/hr x 0.000225 = 0.0025 kg/hr of arsenic emitted from high pressure section of gin

3. Example Calculation to Determine Low Pressure Section Arsenic Emissions

A. Assumptions

1. Arsenic content of low pressure emissions is 1.33 ppm (Section 7.2.2.1)
2. Low pressure section particulate emissions are equal to the difference of total gin particulate emissions minus high pressure emissions as presented in calculation No. 7-2.

B. Calculations

4 bale/hr gin

1. 24.27 kg/hr - 11.26 kg/hr = 13.01 kg/hr of particulate emissions from low pressure section
2. 13.01 kg/hr x $(1.3 \times 10^{-6})$ = $1.73 \times 10^{-5}$ kg/hr of arsenic emissions from low pressure section

7 bale/hr gin

1. 42.91 kg/hr - 19.91 kg/hr = 23 kg/hr of particulate emissions
2. 23 kg/hr x $(1.3\ 10^{-6})$ = $3.06 \times 10^{-5}$ kg/hr of arsenic emissions

12 bale/hr gin

1. 73.56 kg/hr - 34.13 kg/hr = 39.43 kg/hr of particulate emissions
2. 39.43 kg/hr x $(1.3 \times 10^{-6})$ = $5.24 \times 10^{-5}$ kg/hr of arsenic emissions

20 bale/hr gin

1. 122.6 kg/hr - 56.9 kg/hr = 65.7 kg/hr of particulate emissions
2. 65.7 kg/hr x $(1.3 \times 10^{-6})$ = $8.62 \times 10^{-5}$ kg/hr of arsenic emissions

# APPENDIX A-8

## 1. Calculation of ESP Energy Requirements for Glass Plant EBC

### A. Assumptions

1. 0.035 kW of electricity is required per cubic meter/min of gas.
2. There are 8400 hr/yr of operation.
3 Large model plant has 1800 $m^3$/min, medium model plant has 906 $m^3$/min, and the small plant has 453 $m^3$/min.

### B. Calculations

#### 1. Large Model Plant Energy Demand

$$= 1800 \frac{m^3}{min} \times 0.035 \frac{kW}{cmm} \times 56.9 \frac{Btu/min}{kW} \times 8400 \frac{hr}{yr} \times 60 \frac{min}{hr} \times 2.93 \times 10^{-4} \frac{kWh}{Btu}$$

$$= 5.29 \times 10^5 \text{ kWh}$$

#### 2. Medium Model Plant Energy Demand

$$= 906 \frac{m^3}{min} \times 0.035 \frac{kW}{cmm} \times 56.9 \frac{Btu/min}{kW} \times 8400 \frac{hr}{yr} \times 60 \frac{min}{hr} \times 2.93 \times 10^{-4} \frac{kWh}{Btu}$$

$$= 2.69 \times 10^5 \text{ kWh}$$

#### 3. Small Model Plant Energy Demand

$$= 453 \frac{m^3}{min} \times 0.035 \frac{kW}{cmm} \times 56.9 \frac{Btu/min}{kW} \times 8400 \frac{hr}{yr} \times 60 \frac{min}{hr} \times 2.93 \times 10^{-4} \frac{kWh}{Btu}$$

$$= 1.34 \times 10^5 \text{ kWh}$$

## APPENDIX A-9

1. Comparison of Calculated and Measured Osmose Wood Preserving Emissions

   A. Assumptions

      1. From the EPA data on Pennwalt, Inc. 2.6 percent of the arsenic trioxide that is dumped is emitted as a fugitive particulate (Chapter 9, reference 35).
      2. From the EPA/Pedco trip report and the Tennesee State permit data on Osmose, plant uses 14,515 kg/day of arsenic trioxide (Chapter 9, references 14 and 33).
      3. Osmose operates one 8 hour shift per day from EPA/Pedco trip report.
      4. Fabric Filter (FF) control device is 99 percent efficient, scrubber device is 95 percent efficient.

   B. Calculation of Controlled Emissions

      1. $\frac{14{,}515 \text{ kg/day}}{8 \text{ hr/day}} = 1{,}814$ kg/hr
      2. 1,814 kg/hr x 0.026 (emission factor) = 47.2 kg/hr $As_2O_3$ emitted as uncontrolled fugitive
      3. 47.2 kg/hr x 0.01 (FF emissions reduction) = 0.472 kg/hr $As_2O_3$ emitted from the FF
      4. 0.472 kg/hr x 0.05 (scrubber emissions reduction) = 0.024 kg/hr $As_2O_3$ emitted from the scrubber

   C. Measured Controlled Emissions

      1. 0.019 kg/hr $As_2O_3$ as measured during compliance test for TN particulate regulation on 2/81.

## D. Summary

A small increase in the control efficiency, particularly for the FF would make the two emission rates just about equal. For example, if the FF was 0.2 percent more efficient, which is certainly possible with a FF, the two rates would be the same.

## 2. Calculation of Arsenic Emissions from the Voluntary Purchasing Group (VPG) Arsenic Acid Plant

Information learned from the Texas Air Control Board (TACB) regional office in Ft. Worth indicated that in 1980 the VPG plant produced 2.27 million liters of arsenic acid. From other TACB state file data it was learned that the company uses 0.99 kg of arsenic trioxide per liter of arsenic acid produced. Therefore, total arsenic trioxide raw material use was put at 2.25 million kg.

Based on confidential data submitted to EPA on two arsenic chemical plants, an emissions factor of $\frac{8.1 \times 10^{-6}\ \text{kg of arsenic trioxide}}{\text{Mg arsenic trioxide input}}$ was developed. The controls of the VPG plant are very similar to those in use at the plants from which the emissions factor was developed. Inorganic arsenic emissions can, therefore, be expected to be of a similar magnitude. The annual VPG inorganic arsenic emissions were calculated as follows:

$$\frac{8.1 \times 10^{-6}\ \text{As}_2\text{O}_3}{\text{Mg As}_2\text{O}_3\ \text{input}} \times \frac{228\ \text{Mg As}_2\text{O}_3}{\text{yr}} = \frac{0.018\ \text{kg As}_2\text{O}_3}{\text{yr}}$$

The hourly emissions of the VPG plant could not directly be determined because no data were available on the total hours of dumping operations at the plant. As a result the average annual hours of operation were estimated by averaging the operation periods for the other plants in this source category. This average equals 2723 hours per year. Hourly emissions of the VPG plant were then calculated by the following:

$$\frac{0.018\ \text{kg As}_2\text{O}_3}{\text{yr}} \times \frac{1}{2723\ \text{hr/yr}} \times \frac{6.6 \times 10^{-6}\ \text{kg As}_2\text{O}_3}{\text{hr}}$$

In summary, annual inorganic arsenic emissions were determined to be 0.018 kg/yr, while the hourly emission rate was put at $6.6 \times 10^{-6}$ kg/hr. These estimates are consistent with other arsenic acid plants employing similar arsenic trioxide controls.

# APPENDIX B - BASES FOR THE CALCULATION OF ARSENIC EMISSIONS CAPITAL AND ANNUALIZED CONTROL COSTS

The purpose of this appendix is to present the methodologies, assumptions, and supporting data used to estimate capital and annualized costs of arsenic emissions control in each of the source categories. The appendix has been organized to correspond with the arrangement and order of the individual source category chapters in the report. For example, information on the control costs for secondary lead smelting, which is Chapter 6 in the report, would be found in Appendix B-6.

## APPENDIX B-3

### 1. Calculation of Incremental EBC Costs for Primary Copper Smelting Process Emissions Control Systems

As discussed in Chapter 3, three primary copper smelters that are expected to continue operations will not be controlled at the EBC level for arsenic when compliance with the regulatory baseline is achieved. These smelters are Kennecott/Hayden, Magma/San Manuel, and Copper Range/White Pines. Each of these smelters would require spray chamber/gas cooling systems on one or more process offgas streams to reduce the temperature of existing ESP units that currently operate at elevated temperatures.

As an example of the methodology used to estimate the associated incremental EBC costs, consider the Kennecott/Hayden smelter. A schematic diagram of the plant is shown in Figure 1 of Appendix A-3. Currently the roaster and converter offgases are combined and sent to an acid plant unit. The reverberatory furnace offgas stream is sent to an ESP operated at 650°F. Thus, the roaster and converter offgas streams are controlled at the EBC level as defined in Chapter 3, but the reverberatory offgas stream is not. The control equipment required to reach EBC for the reverberatory offgas stream is a spray chamber system capable of cooling the gas to about 110°C (230°F).

The characteristics of the reverberatory furnace offgas stream are:

gas flowrate = 125,000 scfm (59 $Nm^3$/sec)
temperature = 650°F (345°C)
$SO_2$ content = 0.4%
arsenic content = 27.8 mg/$Nm^3$ (13.0 lb/hr)

The purchase cost of a spray chamber system capable of providing the required cooling is obtained using the spray chamber cost equation given in reference 4:

$$\text{Purchase Cost (December 1977) dollars} = 0.235 \times (\text{gas inlet flowrate, acfm}) + 43{,}000$$

For the Kennecott/Hayden reverberatory furnace offgas stream:

$$\text{Purchase Cost (December 1977) dollars} = 0.235 \times \frac{(650 + 460)^\circ R}{(70 + 460)^\circ R} \times 125{,}000 + 43{,}000$$

$$= \$105{,}000 \text{ (December 1977)}$$

The purchase cost estimate is updated to final quarter 1981 dollars:

$$\text{Purchase Cost (final quarter) 1977 dollars} = \$105{,}000 \times \frac{305.3}{204.1}$$

$$= \$157{,}000 \text{ (final quarter 1981)}$$

The required water flowrate for the spray chamber is calculated assuming that the heat removed from the gas stream is transferred to the water as latent heat (i.e., ignore sensible heat effects and assume adiabatic operation). Under this assumption an energy balance yields:

$$\dot{M}_{H_2O} = \frac{\dot{M}_{\substack{gas\\stream}} \times (C_p)_{\substack{gas\\stream}} \times (\Delta T)_{\substack{gas\\stream}}}{\Delta H_{\substack{vaporization\\H_2O}}}$$

where:

$\dot{M}_{H_2O}$ = required water flowrate (gmoles/minute)

$\dot{M}_{\substack{gas\\stream}}$ = offgas flowrate (gmoles/minute)

$C_p$ = specific heat of gas stream (cal/gmole - °K)

$\Delta T$ = desired temperature change in gas stream (°C)

$\Delta H_{\substack{vaporization\\H_2O}}$ = latent heat of vaporization of water

The molar flowrate of the gas stream is calculated using the ideal gas law:

$$\dot{M}_{\substack{gas\\stream}} = \frac{PV}{RT}$$

$$\dot{M}_{\substack{gas\\stream}} = \frac{1 \text{ atm} \times 59 \text{ m}^3\text{/sec} \times 60 \text{ sec/min}}{82.05 \times 10^{-6} \frac{\text{m}^3\text{-atm}}{\text{gmole-°K}} \times 293\text{°K}}$$

$$= 1.5 \times 10^5 \text{ gmole/minute}$$

The specific heat of the gas stream is estimated over the applicable temperature range of 110°C - 345°C using the weighted average specific heat corresponding to a composition typical of a reverberatory offgas:

| | |
|---|---|
| $H_2O$ | 15% |
| $CO_2$ | 8% |
| $O_2$ | 10% |
| $N_2$ | 67% |

Using this approach, $(C_p)_{\substack{gas\\stream}} = 7.5\ \frac{cal}{gmole\text{-}^\circ K}$

The desired temperature change in the gas stream is:

$$(\Delta T)_{\substack{gas\\stream}} = (345 - 110)^\circ C = 235^\circ C$$

The latent heat of vaporization of water is $\Delta H_{\substack{vaporization\\H_2O}} = 9717$ cal/gmole

Substituting into the energy balance equation yields:

$$\dot{M}_{H_2O} = \frac{1.5 \times 10^5 \text{ gmole/min} \times 7.5 \text{ cal/gmole-}^\circ K \times 235^\circ K}{9717 \text{ cal/gmole}}$$

$$= 2.7 \times 10^4 \text{ gmole/min water} = 490 \text{ liters/minute} = 130 \text{ gallons/minute}$$

So the water flowrate required to provide the desired cooling is 130 gpm.

The power required to pump 130 gpm of water to 100 psig (typical for spray chamber) is estimated by the equation:

$$\text{Power (kw)} = \frac{0.746 \times (GPM) \times \Delta P}{3960 \times 0.6}$$

where: GPM = water flowrate, gallons per minute = 130 gpm
$\Delta P$ = required gauge pressure, ft $H_2O$

Substituting into the equation and assuming that the pump operates 8760 hours per year yields:

Energy requirement = $8.3 \times 10^4$ kWh/yr

The total installed capital cost and the annualized cost of the spray chamber are then estimated as shown below.

A. Total Capital Cost

Purchase cost = $157,000
Direct Installation Cost @ 0.5 Purchase Cost = $78,500

Indirect Installation Cost @ 0.5 Purchase Cost = $78,500

Total Capital Cost = 157,000 + 78,500 + 78,500
= $314,000 for spray chamber system

B. Total Annual Cost

1. Operating Labor

a. operator (½ man-hour/shift, $13.80/man-hour)

$$\frac{\$13.80}{\text{man-hour}} \times \frac{1}{2}\,\frac{\text{man-hour}}{\text{shift}} \times 3\,\frac{\text{shift}}{\text{day}} \times 365\,\frac{\text{day}}{\text{yr}} = \$7.7 \times 10^{3}/\text{yr}$$

b. supervision (15% of operator cost)

$$0.15 \times 7.7 \times 10^{3} = \$1.1 \times 10^{3}/\text{yr}$$

2. Operating Materials

- negligible

3. Maintenance

a. labor (½ man-hour/shift, $15,20/man-hour)

$$\frac{\$15.20}{\text{man-hour}} \times \frac{1}{2}\,\frac{\text{man-hour}}{\text{shift}} \times 3\,\frac{\text{shift}}{\text{day}} \times 365\,\frac{\text{day}}{\text{yr}} = \$8.3 \times 10^{3}/\text{yr}$$

b. materials (100% of maintenance labor)

$$1.0 \times 8.3 \times 10^{3} = \$8.3 \times 10^{3}/\text{yr}$$

4. Replacement Parts

- negligible

5. Utilities

a. electricity @ $.0432/kw-hr

$$\frac{\$0.0432}{\text{kw-hr}} \times 8.3 \times 10^{4}\,\frac{\text{kw-hr}}{\text{yr}} = \$3.6 \times 10^{3}/\text{yr}$$

b. cooling water @ $0.10/10^{3}$ gallons

$$\frac{0.10}{10^{3}\ \text{gal}} \times 130\,\frac{\text{gal}}{\text{min}} \times 60\,\frac{\text{min}}{\text{hr}} \times 8760\,\frac{\text{hr}}{\text{yr}} = \$6.9 \times 10^{3}/\text{yr}$$

6. Overhead (@ 80% of total labor)

   $0.8\ (7.6 + 1.1 + 8.3) \times 10^3\ \$/\text{yr} = \$13.6 \times 10^3/\text{yr}$

7. Property Tax, Insurance, Administration (@ 4% of total capital cost)

   $0.04\ (\$314{,}000) = \$12.6 \times 10^3/\text{yr}$

8. Capital Recovery (@ 16.7% of total capital cost)

   $.167\ (\$314{,}000) = \$52.4 \times 10^3/\text{yr}$

---

Total annual cost of spray chamber system $= (7.6 + 1.1 + 8.3 + 8.3 + 3.6 + 6.9 + 13.6 + 12.6 + 52.4) = \$114.4 \times 10^3/\text{yr}$

## 2. Calculation of Incremental EBC Costs for Primary Copper Smelting Fugitive Emissions Control Systems

As discussed in Chapter 3, most of the primary copper smelters will not be controlled at the EBC level for fugitive arsenic emissions when compliance with the regulatory baseline is achieved. The additional equipment that will be required to reach EBC for fugitive arsenic emissions includes a fabric filter system for furnace tapping ventilation gases, and an air curtain/secondary hood system for controlling converter fugitives.

### A. Capital and Annual Costs for the Furnace Tapping Fabric Filter System

The capital and annual costs for the furnace tapping fabric filter system were estimated using references 1 and 2. The purchase cost of the required fabric filter system was estimated using the log-linear cost curve for fabric filter systems in the non-ferrous smelting industry shown in reference 1. A regression model was used to standardize cost interpolations from the curve. Corrected to final quarter 1981 dollars, the purchase cost regression model is represented by:

$$\text{Purchase Cost} = 0.0713\ Q^{0.7854}$$

where: $Q$ = gas flowrate (acfm)
Purchase Cost = thousands of final quarter 1981 dollars

The purchase cost estimates include the flange to flange fabric filter module, the bags, fans, motors, ladders, walkway, screw conveyor, dampers, and expansion duct. They do not include other ductwork or new stack costs.

The total installed capital cost was estimated as 2.56 times the purchase cost using the information in reference 2. The annualized costs for the system were estimated using the algorithm in reference 2. The following labor requirements, wages, and utility costs were assumed:

- fabric filter system operating labor is \$13.80/man-hour and 3 man-hour/shift are required
- fabric filter system maintenance labor is \$15.20/man-hour and 1.5 man/hour/shift are required
- electricity cost is \$.04/kWh, and the fabric filter system operates at a $\Delta P$ of 14 inches of water.

As an example of the cost algorithm, the Kennecott/Hayden smelter is considered. The ventilation gas flowrate for the furnace tapping operation at Kennecott/Hayden is unknown. However, the ventilation flowrate at ASARCO/Tacoma is known to be $1300 \text{ Nm}^3\text{/min}$ (46,000 scfm). The assumption is made that the furnace ventilation gas flowrate at a plant is proportional to the plant capacity. Thus,

$$\begin{bmatrix}\text{Estimated ventilation}\\ \text{flow at Kennecott/Hayden}\end{bmatrix} = \begin{bmatrix}\text{Ventilation flow}\\ \text{at ASARCO/Tacoma}\end{bmatrix} \times \left[\frac{73{,}000 \text{ Mg/yr copper}}{91{,}000 \text{ Mg/yr copper}}\right]$$

$$= 1040 \text{ Nm}^3\text{/min} = 37{,}000 \text{ scfm.}$$

Using this gas flowrate and the purchase cost equation shown above, one finds:

$$\begin{bmatrix}\text{Purchase cost of furnace}\\ \text{ventilation fabric filter}\\ \text{system at Kennecott/Hayden}\end{bmatrix} = \$276 \times 10^3$$

$$\begin{bmatrix}\text{Total installed capital cost}\\ \text{of furnace ventilation fabric}\\ \text{filter system at Kennecott/Hayden}\end{bmatrix} = 2.56 \times \$276 \times 10^3 = \$707 \times 10^3$$

The total annualized cost for the fabric filter system at Kennecott/Hayden is estimated to be $\$363 \times 10^3$/yr. The breakdown of the costs is shown in Table 1.

## B. Capital and Annual Costs for Converter Fugitive EBC Control

Each of the primary copper smelters considered in this study except for ASARCO/El Paso will not be controlled at the EBC level for converter fugitive arsenic emissions when compliance with the regulatory baseline is achieved. The equipment needed to reach EBC for converter fugitives at these plants consists of air curtain/secondary hood systems followed by particulate removal in fabric filter units. The capital and annual costs of the air curtain/secondary hood systems are estimated using the actual costs reported by ASARCO[3] for the ASARCO/Tacoma plant. The capital and annual costs of the fabric filter systems used to collect particulate matter captured by these devices are estimated using the method shown in Appendix B-3, Section 2A.

The estimated cost of EBC converter fugitive control depends on the number of converters at the plant in question. The ASARCO/Tacoma plant has three converters, and the air curtain/secondary hooding design is based on having two of the three converters operating at any one time. The total installed capital costs for the air curtain/secondary hood system reported by ASARCO are summarized in Table 2. Updated to final quarter 1981 dollars, the cost data can be summarized by the equation:

$$\text{Total installed capital cost} = \$\,[3038 + (n-1)\,1063] \times 10^3$$

where $n$ = the number of converters at the plant ($n = 3$ at ASARCO/Tacoma)

The annualized costs for the air curtain/secondary hood systems are estimated using the following assumptions:

- the operating labor requirement per converter 1 man-hour/shift @ $13.80/man-hour
- the maintenance labor requirement per converter is 0.5 man-hour/shift @ $15.20/man-hour
- the energy requirement per converter is estimated by analogy to the ASARCO/Tacoma plant, where the main fan for a 3-converter system requires a 1250 hp drive. The cost of energy is $0.04/kWh
- supervisory labor cost is estimated as 15 percent of the operating labor cost

## TABLE 1. TOTAL ANNUALIZED COSTS FOR FURNACE FABRIC FILTER SYSTEM AT KENNECOTT/HAYDEN

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DIRECT OPERATING COSTS

1. Operating Labor

   a. Operator

$$\frac{\$13.80}{\text{man-hour}} \times 3\ \frac{\text{man-hour}}{\text{shift}} \times 3\ \frac{\text{shift}}{\text{day}} \times 365\ \frac{\text{day}}{\text{yr}} = \$45.3 \times 10^3/\text{yr}$$

   b. Supervisor

$$0.15\ (1a.) = 0.15 \times \$45.3 \times 10^3/\text{yr} = \$6.8 \times 10^3/\text{yr}$$

2. Maintenance

   a. Labor

$$\frac{\$15.20}{\text{man-hour}} \times 1.5\ \frac{\text{man-hour}}{\text{shift}} \times 3\ \frac{\text{shift}}{\text{day}} \times 365\ \frac{\text{day}}{\text{yr}} = \$25.0 \times 10^3/\text{yr}$$

   b. Materials

$$1.0\ (1a.) = 1.0 \times \$45.3 \times 10^3/\text{yr} = \$45.3 \times 10^3/\text{yr}$$

3. Utilities

$$\frac{\$0.04}{\text{kWh}} \times 8.9 \times 10^5\ \text{kWh} = \$35.5 \times 10^3/\text{yr}$$

4. Overhead

$$\begin{aligned} 0.8\ (\text{total labor}) &= \$0.8\ (45.3 + 6.8 + 25.0) \times 10^3/\text{yr} \\ &= \$61.7 \times 10^3/\text{yr} \end{aligned}$$

5. Property Tax, Insurance, Administration

$$\begin{aligned} .04\ (\text{total installed capital cost}) &= 0.04\ (707 \times 10^3) \\ &= \$28.3 \times 10^3/\text{yr} \end{aligned}$$

6. Capital Recovery

$$\begin{aligned} 0.163\ (\text{total installed capital cost}) &= 0.163\ (707 \times 10^3) \\ &= \$115.2 \times 10^3/\text{yr} \end{aligned}$$

---

$$\text{Total Annualized Cost} = (45.3 + 6.8 + 25.0 + 45.3 + 35.5 + 61.7 + 28.3 + 115.2) = \$363 \times 10^3/\text{yr}$$

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## TABLE 2. TOTAL INSTALLED CAPITAL COST OF THE ASARCO/TACOMA AIR CURTAIN/SECONDARY HOOD SYSTEM

| ITEM | REPORTED COST IN AUGUST 1980 DOLLARS[3] | |
|---|---|---|
| | 1st Converter | Other Converters |
| 1. Direct Labor and Materials | | |
| Hood and Door | 249,450 | 264,450/conv |
| Air Curtain System | 72,600 | 69,800/conv |
| Flue System & Fan | 1,018,150 | 182,100/conv |
| Electrical Distribution System | 45,167 | 45,167/conv |
| 2. Engineering | 266,000 | 10,000/conv |
| 3. Contractor's Field Distributables | 283,000 | 86,000/conv |
| 4. Escalation | 279,000 | 175,000/conv |
| 5. Contingencies | 230,300 | 78,650/conv |
| 6. Fees, etc. | 69,000 | 23,500/conv |
| 7. Taxes | 35,000 | 19,000/conv |
| Total of items 1-7 | 2,638,000 | 908,500/conv |

## TABLE 3. SUMMARY OF EBC CONTROL COSTS FOR FUGITIVE ARSENIC EMISSIONS FROM COPPER CONVERTERS (Final quarter 1981 dollars)

| | | AIR CURTAIN/SECONDARY HOOD | | FABRIC FILTER | | ENTIRE EBC CONTROL SYSTEM | |
|---|---|---|---|---|---|---|---|
| # Converters | Required Air Flow (acfm) | Installed Total Capital Cost $10^3$ $ | Annual Cost $10^3$ $/yr | Installed Total Capital Cost $10^3$ $ | Annual Cost $10^3$ $ | Installed Total Capital Cost $10^3$ $ | Total Annual Cost of System $10^3$ $/yr |
| 2 | 133,000 | 4,146 | 967 | 1,930 | 683 | 6,076 | 1,650 |
| 3 | 100,000 | 5,209 | 1,245 | 2,659 | 895 | 7,868 | 2,140 |
| 4 | 267,000 | 6,272 | 1,523 | 3,337 | 1,096 | 9,609 | 2,619 |
| 5 | 333,000 | 7,335 | 1,802 | 3,969 | 1,288 | 11,304 | 3,090 |
| 6 | 400,000 | 8,398 | 2,080 | 4,583 | 1,477 | 12,981 | 3,557 |
| 7 | 467,000 | 9,461 | 2,358 | 5,176 | 1,661 | 14,637 | 4,019 |

- maintenance material costs are estimated as 100 percent of maintenance labor costs

- the cost of replacement parts is negligible

- overhead costs are estimated as 80 percent of total labor costs

- property taxes, insurance, and administration are estimated as 4 percent of the total installed capital costs

- the capital recovery factor is 0.167.

The fabric filter system costs are estimated as shown in Appendix B-3, Section 2A. The flowrate Q is estimated by analogy to the flow requirement at ASARCO/Tacoma. The ASARCO design flowrate of 200,000 acfm assumes that at any time, 2 out of 3 converters could possibly require the maximum possible individual converter flowrate of 100,000 acfm. Thus, the design flowrate for an n-converter smelting plant was estimated using the equation:

$$Q = n \times \frac{2}{3} \times 100{,}000 \text{ acfm}$$

The total installed capital costs and total annual costs for copper smelters having from 2 to 7 converters are summarized in Table 3. As an example, the annual cost of the air curtain/secondary hood system with a fabric filter system for the Kennecott/Hayden plant (three converters) is $2,140,000.

## REFERENCES FOR APPENDIX B-3

1. U. S. Environmental Protection Agency. Arsenic Emissions from Primary Copper Smelters - Background Information for Proposed Standards. Preliminary Draft. Research Triangle Park, N. C. February, 1981.

2. Vatavuk, William M., and Robert B. Neveril. Factors for Estimating Capital and Operating Costs. Chemical Engineering. November 3, 1980.

3. Marsh, A. O., Jr. ASARCO Incorporated: Converter Secondary Hooding/Tacoma Plant. Salt Lake City, Utah. January 22, 1981.

4. Vatavuk, William M., and Robert B. Neveril. Estimating the Size and Cost of Gas Conditioners. Chemical Engineering. January 26, 1981.

# APPENDIX B-5

## 1. Calculation of Incremental EBC Costs for the New Jersey Zinc Plant

The equipment required for the New Jersey zinc plant to reach EBC for arsenic control consists of a spray chamber to cool the waelz kiln offgas stream prior to collection in the existing fabric filter unit. The total installed capital cost and the annualized operational cost of the spray chamber system were estimated using the methods shown in Section 1 of Appendix B-3. The 220,000 scfm waelz kiln offgas stream needs to be cooled from 140 to 110°C (280 to 230°F) prior to baghouse treatment. Using the methods shown in Section 1 of Appendix B-3 and assuming the same flue gas composition, the required water flowrate for the spray chamber system is 32 gpm, the total installed capital cost is $342,000 (final quarter 1981 dollars), and the total annual cost of operation is $112,000.

# APPENDIX B-6

## 1. Basis of Cost Estimates for Secondary Lead Smelters

MRI[1] provided the following cost estimate for a single scrubber to control $SO_2$ emissions from a typical small and medium sized lead smelter.

Capital Costs:

| | |
|---|---|
| Scrubber, with installation | $300,000 |
| Pump | 20,000 |
| Stack | 5,000 |
| TOTAL | $325,000 |

Annualized Costs:

| | |
|---|---|
| Capital charges ($325,000 x 0.13147, assuming 10 percent for 15 years) | $ 42,700 |
| Operating labor | 18,100 |
| General maintenance | 34,600 |
| Electricity-fan power | 57,900 |
| Electricity-pump power | 6,100 |
| Water | 26,900 |
| Overhead | 28,300 |
| Property tax, insurance | 13,000 |
| TOTAL | $227,600 |

Notice that the annualized cost does not include waste disposal costs.

These costs were derived from data submitted by Tonolli Corporation and General Battery during the secondary lead NSPS revision project. These scrubber costs represent a scrubber sized to handle approximately 50,000 acfm with a design ΔP of 12 inches water and a slurry flow rate of 1,500 gpm. Capital costs for the three plant sizes used to model arsenic emissions were derived from the above data using scaling factors. Analysis of the cost data in GARD[2] show that the cost of scrubbers follow an 0.6 exponent.

$$\text{Cost of a} = \text{Cost of b} \left(\frac{\text{Capacity of a}}{\text{Capacity of b}}\right)^{0.6}$$

Using this rule, capital costs for scrubbers for small, medium, and large secondary lead smelters were developed. It was assumed that two medium sized scrubbers would be needed by the large plant. Operating costs were estimated from the MRI data assuming that maintenance was a fixed proportion of total installed costs, electricity costs would vary linearly with scrubber size, and operating labor would remain constant for each scrubber.

The costs given by MRI for water seemed very high and probably included the lime slurry costs. This cost was adjusted downward to reflect water usage alone rather than limestone or caustic usage. Using these procedures the costs in Table 1 were derived:

TABLE 1. COSTS OF SCRUBBERS TO CONTROL SECONDARY LEAD SCRUBBERS

| Plant Size | Small | Medium | Large | |
|---|---|---|---|---|
| Flow dscfm | 20,000 | 36,000 | 72,000 | |
| acfm | 24,000 | 43,000 | 86,000 | Split into two streams |
| Total installed cost | $194,000 | 278,000 | 556,000 | 2 scrubbers |
| Annualized capital cost @ 13147 | $ 27,600 | 39,570 | 73,097 | |
| Operating labor | $ 34,600 | 34,600 | 69,200 | |
| General maintenance @ 11% of cap | 37,800 | 54,200 | 108,400 | |
| Electricity costs for pumps and fan | 31,000 | 56,000 | 112,000 | @ $.04 kwh |
| Water use | 415 | 2,150 | 4,300 | @ $.25/1,000 gallons |
| Overhead | 18,300 | 26,200 | 52,400 | |
| Property taxes + ins. @ 4% | 8,400 | 12,040 | 24,080 | |
| Total Annualized Cost | $158,125 | $224,760 | $443,477 | |

## POWER REQUIREMENTS FOR PUMPS AND FANS

### FANS

Assume scrubber pressure drop is 12-15 inches water.
Assume stack pressure drop is 3 inches water.
Assume ductwork damper elbows etc. is 9 inches water.
(Approximately 300 feet equivalent length of ductwork)

TOTAL PRESSURE DROP is 27 inches water.

| Plant | Small | Medium | Large |
|---|---|---|---|
| Flow ACFM | 24,000 | 33,000 | 66,000 |
| ΔP " water | 27 | 27 | 27 |
| Fan motor HP (from GARD) | 162 | 288 | 576 |

### PUMP POWER REQUIREMENTS

Assume scrubber water flow is 10 gpm per 1000 $ft^3$ gas flow
Total head ≅ 100 feet. Pump efficiency ≅ 50%.

| Pump |  |  |  |
|---|---|---|---|
| HP | 12 | 22 | 44 |

| Total Power requirements - Fan and Pump |  |  |  |
|---|---|---|---|
| HP | 174 | 310 | 620 |
| kwh/h | 130 | 232 | 463 |

### WATER USE FOR SCRUBBERS

Incoming exhaust gases from fabric filter has a water content of 3% @ 176°F.

At the scrubber exit, the exhaust gases will be saturated with water. The estimated exit temperature for the scrubber is 100°F.

At 100°F 1 pound of dry air can contain 0.044 lbs of water.

3% water by volume = .03 moles/mole of mixture
= .03 moles/.97 moles dry air
= .03 x 10 lb/mole/.97 x 29 lbs/mole
= .54 lb $H_2O$/28.13 lbs dry air
= .019 lbs $H_2O$/lb dry air.

Therefore the amount of water absorbed by the exhaust gases from the scrubber will be (.044 - .019) lbs per lb of dry gas.

.025 lb/lb dry gas ≅ 2 lbs $H_2O$/1000 scf.

## WATER USE BY PLANT SIZE

| Plant Size | Small | Medium | Large |
|---|---|---|---|
| Flow dscfm | 20,000 | 36,000 | 76,000 |
| Water use gpm | 4.8 | 8.6 | 17.3 |
| Gallons/year @ 6,000 hours operation | $1.7 \times 10^6$ | $3.1 \times 10^6$ | $6.2 \times 10^6$ |

## YEARLY ARSENIC REMOVALS BY SCRUBBERS

The model plant emissions factors are as follows:

| Plant | Small | Medium | Large |
|---|---|---|---|
| Arsenic from fabric filter lb/hr | .12 | .2 | .4 |
| Arsenic from fabric filter/ scrubber combination lb/hr | .05 | .08 | .16 |
| Arsenic removal lb/hr | .07 | .12 | .24 |
| Yearly removal lbs | 420 | 720 | 1,440 |

## Particulate removal

Test data indicates that the fabric filter/scrubber combination has higher particulate emissions than the fabric filter alone. Therefore, no incremental particulate removal can be estimated. Solid waste disposal costs could be significant if the scrubber was used for joint $SO_2$ and arsenic control. Large amounts of sulfate sludge would be generated which would need to be disposed of.

For a water scrubber - assume arsenic content of particulate matter = 3.2 percent. Sludge would be thickened to 30 percent prior to disposal. Yearly sludge quantities would be as follows:

| Size | Small | Medium | Large |
|---|---|---|---|
| Dry Particulate tpy | 6.6 | 11.25 | 22.5 |
| Sludge @ 30% | 22 | 37.5 | 75 |

## REFERENCES

1. (DRAFT). Development of NSPS Project Conclusions Report for Secondary Lead Smelting Industry. Prepared by MRI. ESED Project Number 80/33. January 27, 1981. p. 21.

2. Neveril, R. B. Capital and Operating Costs of Selected Air Pollution Control Systems. Prepared for the U. S. Environmental Protection Agency. EPA Publication Number 450/5-8-002.

# APPENDIX B-7

1. Equipment Cost of Long-cone Cyclones for Low Pressure Exhaust Control - 20 bale/hr Gin

## I. References for Cost Data

A. Letter from Furr, R., Anderson-Bigham Sheet Metal Works, Inc. to Brooks, G., Radian Corporation. March 22, 1982.

## II. Calculations

A. From Table 7-2, the arsenic emission rate is 0.072 kg (0.152 lb)/yr. This is to be controlled by 94 percent.

B. Total Low Pressure Flow = 2443 $m^3$/min, therefore the following cyclone arrangement was used:

| Gin Emission Pt. | Airflow ($m^3$/min) | No. of Cyclones |
|---|---|---|
| 6 | 599 | 2 82.6 cm Quads |
| 7 | 594 | 2 82.6 cm Quads |
| 8 | 945 | 3 86.4 cm Quads |
| 9 | 306 | 1 82.6 cm Quad |

C. Cyclone costs are as follows:

- 82.6 cm Quad = \$2464.80/unit x 5 = \$12,324.00
- 86.4 cm Quad = \$2606.90/unit x 3 = 7,820.70

\$20,144.70

D. Control cost-effectiveness is,

$$- \frac{(\$20,144.70) \times (\text{Cap. Recovery factor of } 0.163)}{(0.072) \times (0.94)} =$$

\$48,516/kg of arsenic removed.

2. Bases for the Capital and Annualized Costs of Cotton Gin EBC

I. Bases for Capital Costs

A. Total Direct Equipment Costs (TDEC)

1. Primary Equipment Cost = Vendor Cost Data
2. Taxes = 3% of Primary Equipment Cost
3. Freight = 5% of Primary Equipment Cost

B. Direct Installation Costs (DIC)

1. Foundation & Supports = 6% of TDEC
2. Handling & Erection = 40% of TDEC
3. Electrical = 1% of TDEC
4. Piping = 5% of TDEC

C. Indirect Installation Costs (IIC)

1. Engineering & Supervision = 10% of TDEC
2. Construction & Field = 10% of TDEC
3. Construction Fee = 10% of TDEC
4. Startup & Performance Test = 2% of TDEC
5. Contingencies = 3% of TDEC

D. Total Capital Cost = (TDEC + DIC + IIC)

II. Bases for Annualized Costs

A. Direct Operating Costs

1. Utilities = $0.04/kWh of electricity
2. Waste Disposal - No additional costs as a result of EBC

B. Indirect Operating Costs

1. Taxes & Insurance = 2% of Total Capital Cost
2. G & A = 2% of Total Capital Cost
3. Capital Recovery = 16.3% based on 10% interest/10 yr. equipment life

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References for the cost bases were taken from the following:

1. Vatavuk, W. M. and R. B. Neveril. Chemical Engineering. November 3, 1980. pp. 157-162.

# APPENDIX B-8

## 1. Bases for the Glass Manufacturing EBC Option Cost Analysis

### A. Bases for the Capital Costs

1. The bases for the capital cost of the glass manufacturing EBC option are identical to those presented in Appendix B-7 for cotton gins.

2. All costs were updated to last quarter 1981 dollars using the Chemical Engineering Plant Cost Index published by McGraw Hill. The subcategory used was Equipment, Machinery, and Supports which had an index value of 332.7. The reference for this index is: Chemical Engineering, Volume 89, No. 7. April 5, 1982, p. 7.

3. Costs for gas cooling devices were taken from: Chemical Engineering, Volume 88, No. 2, January 26, 1981, P. 132. These costs were in 1977 dollars which were updated by using the Chemical Engineering Plant Cost Index given in: Chemical Engineering, Volume 85, No. 11, May 8, 1978, p. 190. The index value is 220.9.

4. ESP costs were in 1978 dollars which were updated by using the same index given in: Chemical Engineering, Volume 87, No. 1, January 14, 1980, p. 7. The index value is 247.6.

5. From EPA data on existing glass plants using ESP control devices, on average ESP plate area of 1.1 $ft^2$/scfm was selected to cost out ESP devices for the arsenic glass manufacturing model plants in Chapter 8. The 1.1 value does not represent a plate area designed to equal EBC. It was selected as a conservative value to apply to general ESP cost curves based on plate area. This study did not specify a design plate area associated with EBC. The reference for the 1.1 value is: Glass Manufacturing Plants, Background Information: Proposed Standards of Performance, EPA-450/3-79-005a, U. S. Environmental Protection Agency, June 1979, p. 4-23.

6. Costs for the ESP control devices were taken from the same reference given in No. 5 above except that the correct page is p. 8-58.

B. Bases for the Annualized Costs

1. The bases for annualized costs given in Appendix B-7 for cotton gins are also applicable to glass manufacturing.

2. Labor costs are as follows:

   - Operating labor is $13.80/hr
   - Maintenance labor is $15.20/hr

   These costs were obtained from: Chemical Engineering, Volume 87, No. 22, November 3, 1980, pp. 157-162. They were updated by using the Engineering and Supervision subcategory of the Chemical Engineering Plant Cost Index.

3. For gas cooling devices operating labor is assumed to be zero. Maintenance labor is 0.5 man-hours per shift and maintenance materials is equal to the cost of the labor. Overhead is equal to 80 percent of total labor. The additional parameters of the gas cooler annualized cost are:

   - utilities
   - taxes and insurance
   - G & A
   - capital recovery

4. For the ESP devices operating labor is 1 man-hour per shift. Supervisory labor equals 15 percent of operating labor. Maintenance labor is 0.5 man-hours per shift with maintenance materials equal to the labor cost. Overhead charges equal 80 percent of total labor. The remaining factors addressed in the annualized ESP costs were:

   - utilities
   - taxes and insurance
   - G & A
   - capital recovery

# APPENDIX C - METHODOLOGY FOR THE ECONOMIC IMPACT CALCULATIONS

The purpose of this appendix is to present the methodology used to calculate the economic impacts of the recommended EBC options for the primary copper and zinc smelting, secondary lead smelting, cotton ginning, and glass manufacturing source categories.

## ECONOMIC IMPACT ANALYSIS METHODOLOGY

This arsenic source survey economic impact assessment utilized a methodology based on a simplified price impact analysis. This methodology calculates the revenue and price increases required by model plants to maintain the same net present values (NPV) before and after installation of arsenic-controlling EBC equipment. This revenue calculation relies on a single derived equation that requires several types of input data for each model plant. In addition to the methodology description, this appendix includes a description of the input data used for the price impact analysis.

### A. Revenue and Price Impact Analysis

The purpose of this analysis is to determine the revenue increase that exactly offsets arsenic emissions control costs so that the NPV of the model plant remains constant or the NPV of the incremental cash flow is zero at the stated weighted average cost of capital. In this analysis, capital costs, operating and maintenance costs, investment life, income taxes and inflation need to be taken into account. A nominal discount rate is used for the analysis because it is more intuitive and because most equity capital cost data are available in nominal terms. The use of a nominal discount rate requires that revenues and operating costs be properly inflated. The revenue increase that the analysis calculates is expressed in base year dollars, in this case the fourth quarter of 1981. The required revenue increase is converted to a required unit price increase by dividing the revenue by the annual sales volume. This step requires the assumption that annual sales volume is constant, indicating perfectly inelastic demand.

The derivation of the basic formula for the price impact analysis requires the following assumptions:

- the incremental pollution control investment occurs at the beginning of the base year.
- there is no replacement investment for emission control.
- emission control investments have zero salvage value.
- no differential inflation occurs among the cost or revenue items.
- the weighted average cost of capital and the marginal income tax rate remain constant during the life of the investment.

- depreciation is based on the 1981 Economic Recovery Act, Accelerated Cost Recovery System (ACRS) five-year rates.
- a 10 percent investment tax credit is applicable on the total EBC investment and is realized in the year following the investment.
- NPV of the model plant remains constant at the stated weighted cost of capital.

The derivation of the basic formula of the methodology is presented in the context of the standard definition of NPV:

$$NPV = -I_o + \sum_{y=1}^{n} \frac{CF_y}{(1+d)^y} \qquad (1)$$

where,

NPV = net present value (in base year dollars)
$I_o$ = investment (period y=0)
y = time period
n = investment life
$CF_y$ = projected operating cash flows in period y
d = discount rate or cost of capital

Cash flow, CF, is defined as revenues, R, less operating and maintenance costs, OM, less income taxes, T.

$$CF_y = R_y - OM_y - T_y \qquad (2)$$

Interest expense is excluded because interest and its tax effect are accounted for in the discount rate. Revenue and operating costs will inflate at the same rate, thus, nominal revenue (and O&M) equals the product of the inflation factor, $(1+inf)^y$, and constant dollar value in y=0 dollars. That is,

$$R_y = (R_o) \ (1+inf)^y \qquad (3)$$

and,

$$OM_y = (OM_o) \ (1+inf)^y \qquad (4)$$

Income taxes, $T_y$, are computed on the basis of nominal current income. Income taxes are defined to equal the tax rate, t, times taxable net income. The investment tax credit ($ITC_y$) is subtracted directly from income taxes.

Taxable income equals revenue less operating and maintenance expense less depreciation. Thus,

$$T_y = t(R_y - OM_y - D_y) - ITC_y \tag{5}$$

Substituting the income tax Equation (5) into the cash flow Equation (2) yields the following expanded expression for cash flow.

$$CF_y = R_y - OM_y - T_y \tag{6a}$$

$$= R_y - OM_y - t(R_y - OM_y - D_y) + ITC_y \tag{6b}$$

$$= R_y - OM_y - tR_y + tOM_y + tD_y + ITC_y \tag{6c}$$

$$= (1-t)R_y - (1-t)OM_y + tD_y + ITC_y \tag{6d}$$

Further, by substitution of Equations (3) and (4) into (6d), operating cash flow, $CF_y$, may be expressed by:

$$CF_y = (1-t)R_o(1+inf)^y - (1-t)OM_o(1+inf)^y + tD_y + ITC_y \tag{7}$$

Net present value can now be defined in terms of revenue, operating and maintenance costs and income tax effects on revenue, operating costs, and investment including effects of depreciation and the investment tax credit.

By substitution of Equation (7) into Equation (1),

$$NPV = -I_o + \sum_{y=1}^{n} \frac{(1-t)R_o(1+inf)^y - (1-t)OM_o(1+inf)^y + tD_y + ITC_y}{(1+d)^y} \tag{8}$$

Equivalently, each term under summation can be summed individually so that

$$NPV = -I_o + \sum_{y=1}^{n} \frac{(1-t)R_o(1+inf)^y}{(1+d)^y} - \sum_{y=1}^{n} \frac{(1-t)OM_o(1+inf)^y}{(1+d)^y} + \sum_{y=1}^{n} \frac{ITC_y + tD_y}{(1+d)^y} \tag{9}$$

With Equation (9), it is possible to solve for the annual revenue requirement, $R_o$, (in base year dollars) that is equivalent to incremental emissions control investment, $I_o$, and annual operating and maintenance costs, $OM_o$. First, it is necessary to impose the constraint that incremental NPV=0 and helpful to rearrange terms on the right hand side of Equation (9) so that revenue, operating costs and investment related items are grouped,

$$0 = \sum_{y=1}^{n} \frac{(1-t)R_o(1+inf)^y}{(1+d)^y} - \sum_{y=1}^{n} \frac{(1-t)OM_o(1+inf)^y}{(1+d)^y} - I_o + \sum_{y=1}^{n} \frac{ITC_y + tD_y}{(1+d)^y} \tag{10}$$

Next, the terms related to emissions control investment are isolated. Assuming a 10 percent investment tax credit in the year after investment and five-year ACRS rates the investment, investment tax credit, and depreciation terms on the right hand side of Equation (10) can be expressed as a product of a constant, TAXF, and $I_o$.

$$I_o - \sum_{y=1}^{n} \frac{ITC_y + tD_y}{(1+d)^y} = I_o \left[ 1 - \frac{(.1+.15t)}{(1+d)} - \frac{.22t}{(1+d)^2} - \frac{.21t}{(1+d)^3} - \frac{.21t}{(1+d)^4} - \frac{.21t}{(1+d)^5} \right] \tag{11}$$

$$= I_o \{TAXF\} \tag{12}$$

where TAXF is the sum of terms in brackets. TAXF is a constant that can be repeatedly applied to different investments so long as the tax rate, discount rate and ACRS life remain the same.

Next, $I_o$ {TAXF} is substituted into Equation (10), the constant terms are moved outside their summations, and $R_o$ is isolated on the left hand side of the equation. $R_o$ is then expressed as

$$R_o = \frac{(1-t)OM_o \sum_{y=1}^{n} \frac{(1+inf)^y}{(1+d)^y} + I_o \{TAXF\}}{(1-t) \sum_{y=1}^{n} \frac{(1+inf)^y}{(1+d)^y}} \tag{13}$$

Simplifying Equation (13) results in

$$R_o = OM_o + \frac{I_o\ TAXF}{(1-t) \sum_{y=1}^{n} \left[ \frac{1+inf}{1+d} \right]^y} \tag{14}$$

Equation (14) is the equation used to calculate the annual revenue increase that exactly offsets EBC capital and operating costs so that the NPV of the firm remains constant.

The unit price increase that the model plant needs to realize this annual revenue increase is

$$PI = \frac{R_o}{Q_o} \tag{15}$$

where, $PI$ = the unit price increase in base year dollars
$R_o$ = the required annual revenue increase in base year dollars
$Q_o$ = annual sales volume in units

Finally, the percentage increase in unit price is calculated using the formula

$$PPI = \frac{PI}{P_o} \times 100 \qquad (16)$$

where, $PPI$ = percent unit price increase
$PI$ = unit price increase in base year dollars
$P_o$ = pre-EBC unit price in base year dollars

Equations (14), (15), and (16) were used to analyze the effects of arsenic emission controls.

## B. EBC Capital and Operating Costs

The incremental capital and annualized costs for arsenic EBC are provided in Chapters 3 - 9. The capital costs consisted of the incremental capital outlay, stated in 1981 fourth quarter dollars, required for the technologies needed by the various industries to meet the EBC arsenic emission levels. The control equipment has a useful life of ten years except where indicated. The annualized costs also are stated in 1981 fourth quarter dollars and represent the incremental annual operating and maintenance costs incurred in association with the EBC equipment.

The annual inflation rate used in this analysis was 6.4 percent for all industries. This level of price inflation as measured by the broad-based GNP deflator is the forecast for the next three to five years by the Value Line Investment Survey.

These costs are summarized in Tables 1 through 5.

## C. Product Prices

Information concerning product prices before installation of EBC equipment was needed to calculate the percent price increase caused by the controls. All price data were converted to 1981 fourth quarter dollars. The following sources of price data were used:

- Cotton: "Supplement for 1981 to Statistics on Cotton and Related Data 1960-1978." U.S. Department of Agriculture, Economic Statistics Service.
- Copper, Lead and Zinc: "Minerals Yearbook" Volume I, Metals and Minerals, 1978-79. U.S. Department of the Interior.

### TABLE 1. OPERATING AND FINANCIAL CHARACTERISTICS OF PRIMARY COPPER SMELTER MODEL PLANTS

| MODEL PLANT | ANNUAL OUTPUT[a] (Gg) | BASELINE PRICE (dollars per kg) | EBC CAPITAL COST (000 dollars) | ANNUAL EBC OPERATING COST (000 dollars) | MARGINAL TAX RATE (percent) | WEIGHTED COST OF CAPITAL (percent) |
|---|---|---|---|---|---|---|
| ASARCO/Hayden | 130.4 | 2.34 | 12,620 | 1,543 | 47 | 11.5 |
| Kennecott/Hayden | 58.4 | 2.34 | 8,889 | 1,148 | 47 | 11.5 |
| Kennecott/Hurley | 58.4 | 2.34 | 10,316 | 1,281 | 47 | 11.5 |
| Kennecott/McGill | 36.0 | 2.34 | 6,562 | 866 | 47 | 11.5 |
| Kennecott/Garfield | 203.2 | 2.34 | 11,482 | 1,414 | 47 | 11.5 |
| Phelps Dodge/Morenci | 128.8 | 2.34 | 15,945 | 1,927 | 47 | 11.5 |
| Phelps Dodge/Douglas | 92.0 | 2.34 | 11,304 | 1,248 | 47 | 11.5 |
| Phelps Dodge/Ajo | 51.2 | 2.34 | 8,499 | 1,077 | 47 | 11.5 |
| Phelps Dodge/Hidalgo | 101.6 | 2.34 | 7,126 | 928 | 47 | 11.5 |
| White Pines, Michigan | 65.6 | 2.34 | 7,982 | 1,211 | 47 | 11.5 |
| Magma/San Manuel | 144.8 | 2.34 | 8,013 | 1,036 | 47 | 11.5 |
| Inspiration/Miami | 108.8 | 2.34 | 12,457 | 1,524 | 47 | 11.5 |
| Cities Services/Copperhill | 16.0 | 2.34 | 6,329 | 844 | 47 | 11.5 |

[a] Output assumes 80 percent utilization of capacity.

## TABLE 2. OPERATING AND FINANCIAL CHARACTERISTICS OF MODEL COTTON GINS

| MODEL | SIZE (Mg per year) | BASELINE PRICE (dollars per kg) | EBC CAPITAL COST (000 dollars) | ANNUAL EBC OPERATING COST (000 dollars) | MARGINAL TAX RATE (percent) | WEIGHTED COST OF CAPITAL (percent) |
|---|---|---|---|---|---|---|
| 1 | 108.7 | 1.71 | 23.0 | 1.15 | 18 | 10.5 |
| 2 | 435.0 | 1.71 | 34.5 | 2.17 | 31 | 10.0 |
| 3 | 1,087.5 | 1.71 | 60.9 | 4.98 | 31 | 10.0 |
| 4 | 1,805.0 | 1.71 | 81.1 | 6.18 | 47 | 9.3 |

## TABLE 3. OPERATING AND FINANCIAL CHARACTERISTICS OF GLASS MANUFACTURING MODEL PLANTS

| MODEL PLANT | | SIZE[a] (Gg per year) | BASELINE PRICE (dollars per Mg) | EBC CAPITAL COST (000 dollars) | ANNUAL EBC OPERATING COST (000 dollars) | MARGINAL TAX RATE (percent) | WEIGHTED COST OF CAPITAL (percent) |
|---|---|---|---|---|---|---|---|
| Glassware: | Small | 15.9 | 1,320 | 1,500 | 163.1 | 47 | 9.9 |
| TV Tubes: | Medium | 31.7 | 1,408 | 2,300 | 203.7 | 47 | 9.9 |
| | Large | 63.5 | 1,408 | 3,000 | 246.1 | 47 | 9.9 |
| Bulb Blanks: | Medium | 31.7 | 968 | 2,300 | 203.7 | 47 | 9.9 |
| | Large | 63.5 | 968 | 3,000 | 246.1 | 47 | 9.9 |

[a] Based on 350 operating days per year.

TABLE 4. OPERATING AND FINANCIAL CHARACTERISTICS OF SECONDARY LEAD SMELTER MODEL PLANTS

| MODEL PLANT | ANNUAL OUTPUT (Mg) | BASELINE PRICE (dollars per kg) | EBC CAPITAL COST (000 dollars) | ANNUAL EBC OPERATING COST (000 dollars) | MARGINAL TAX RATE (percent) | WEIGHTED COST OF CAPITAL (percent) |
|---|---|---|---|---|---|---|
| Small | 9,090 | 0.90 | 209 | 99.8 | 47 | 10.5 |
| Medium | 18,180 | 0.90 | 297 | 146.7 | 47 | 10.5 |
| Large | 36,360 | 0.90 | 594 | 293.3 | 47 | 10.5 |

TABLE 5. OPERATING AND FINANCIAL CHARACTERISTICS OF A ZINC OXIDE PLANT

| MODEL PLANT | ANNUAL OUTPUT (Mg) | BASELINE PRICE (dollars per kg) | EBC CAPITAL COST (000 dollars) | ANNUAL EBC OPERATING COST (000 dollars) | MARGINAL TAX RATE (percent) | WEIGHTED COST OF CAPITAL (percent) |
|---|---|---|---|---|---|---|
| 1 | 30,000 | 1.01 | 342 | 55.2 | 47 | 10.5 |

- Glass: "Glass Manufacturing Plants Background Information: Proposed Standards of Performance," June 1979, EPA-450/3-79-005a.

Product prices for each model plant are summarized in Tables 1 through 5.

## D. Discount Rates

For the purpose of this analysis the discount rates used to make the calculations were the model plants' weighted average cost of capital. Weighted average cost of capital is calculated using the formula

$$k_a = k_d(1-t)(W_d) + k_e(W_e)$$

where,

$k_a$ = weighted average cost of capital
$k_d$ = before tax cost of debt
$t$ = marginal income tax rate
$W_d$ = weight of debt in total capital structure
$k_e$ = cost of equity
$W_e$ = weight of equity in total capital structure

Different weights of debt and equity were assigned to model plants, depending on the industry. A before-tax debt cost of 9 percent was used for the metals and glass model plants. A higher before-tax debt cost of 13 percent was used for the cotton gin model plants because of their lack of access to the bond market and their consequent reliance on local commercial banks. Equity costs varied on an after-tax basis between 10.4 and 14.0 percent among the different industries. Weighted average costs of capital are summarized in the model plant data in Tables 1 through 5.